

NASA CONTRACTOR REPORT

NASA CR-614



NASA-CR-

0099408



TECH LIBRARY KAFB, NM

LOAN COPY: RETURN TO
AFWL (WLIL-2)
KIRTLAND AFB, N MEX

LIFE SUPPORT SYSTEM FOR SPACE FLIGHTS OF EXTENDED TIME PERIODS

*by Life Support Project, Life Sciences Dept.,
R. C. Armstrong, Program Manager*

*Prepared by
GENERAL DYNAMICS
San Diego, Calif.
for Langley Research Center*





0099408

NOV 1964

LIFE SUPPORT SYSTEM FOR SPACE FLIGHTS
OF EXTENDED TIME PERIODS

By Life Support Project, Life Sciences Dept.,
R. C. Armstrong, Program Manager

Distribution of this report is provided in the interest of
information exchange. Responsibility for the contents
resides in the author or organization that prepared it.

Prepared under Contract No. NAS 1-2934 by
GENERAL DYNAMICS
San Diego, Calif.

for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 - Price \$6.25

FOREWORD

At some future date, a crew will launch into space on a mission of planned duration of many months. The well being of the crew and the success of the mission will depend to large extent upon the ability of the life support system to maintain a pre-defined environment throughout the changing physical and functional phases of the flight. A comprehensive program of ground and flight testing of the equipment will be required in preparation for these space operations. The first step envisioned by the NASA in the evolution of an advanced life support system was the design and fabrication of an integrated operable four-man prototype mounted in a laboratory test bed designed for conduct of long duration manned and unmanned tests. The test bed must provide flexibility for conducting integrated complete life support system testing and still accept updating of the original system to incorporate improvements in life support systems technology as they evolve. This report documents the analysis, design, development, fabrication, and initial testing of this first prototype physical-chemical life support system.

The system is a major step forward in reducing the logistics requirements of manned space flight by regenerating oxygen from carbon dioxide and recovering pure water from liquid wastes.

The heat rejection of a dynamic power supply is simulated and utilized wherever practicable to reduce the requirement for electrical resistance heaters, a design feature which can materially reduce the overall weight of flight systems. Equipment is packaged and installed in a realistic manner to facilitate operational testing and evaluation.

The experience gained during this development program indicates that continued progress toward systems for missions of extended duration will require a significantly expanded effort in the area of equipment simplification, quality, durability and maintainability.

Major LSS Project Contributors

R. C. Armstrong	S. J. McCunney
J. R. Burnett	B. F. North
G. L. Drake	E. J. Russ
D. L. Hobart	W. J. Sevier
B. W. Hryekewicz	J. A. Steele
C. D. King	C. D. Strode
D. Krause	D. W. Vorbeck

Major Subcontractors

Chicago Bridge and Iron Company, Salt Lake City, Utah
Test Bed

Electric Boat Division, General Dynamics Corporation, Groton, Connecticut
Water Filtration Unit

Electromechanical Division, Thompson Ramo Wooldridge Inc., Cleveland, Ohio
CO₂ Reduction Unit
Cabin Air-Water Separator

General Electric Company, Valley Forge Space Technical Center, Philadelphia, Pennsylvania
Water Electrolysis Unit

Hamilton Standard Division, United Aircraft Corporation, Windsor Locks, Connecticut
Air-Evaporation Water Recovery Units
CO₂ Concentration Unit

C. G. Hokanson Co., Inc., Los Angeles, California
Fluid Cooling and Pumping Unit
Fluid Heating and Pumping Unit

MRD Division, General American Transportation Corporation, Niles, Illinois
Catalytic Burner
Waste Management Equipment

Whirlpool Corporation, St. Joseph, Michigan
Food Management Equipment

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION AND SUMMARY	1-1
1.1 Program Objectives	1-1
1.2 System Requirements	1-1
1.3 Model Criteria	1-2
1.3.1 Mission Model	1-2
1.3.2 Spacecraft Model	1-3
1.3.3 Crew Model	1-4
1.4 Tradeoff Techniques	1-7
1.4.1 Candidate Systems	1-7
1.4.2 Urine Systems	1-7
1.4.3 Urine System Ratings	1-7
1.4.4 Wash Water System	1-7
1.4.5 Condensate System	1-8
1.4.6 Integrated Water Recovery System	1-8
1.4.7 Rating the Integrated Systems	1-9
1.5 Program Control	1-13
1.6 Summary of Selected Subsystems	1-14
1.6.1 Thermal Control	1-14
1.6.2 Atmospheric Control	1-14
1.6.3 Water Management	1-18
1.6.4 Waste Management	1-19
1.6.5 Personal Hygiene	1-20
1.6.6 Food Management	1-20
1.6.7 Instrumentation and Control	1-21
1.6.8 Test Bed	1-21
1.6.9 System Weight, Volume, and Power	1-22
1.7 System Tests	1-22
1.7.1 Test Procedure	1-22
1.7.2 Test Results	1-24
1.8 Conclusions and Recommendations	1-25
1.8.1 Leakage	1-26
1.8.2 Water Treatment	1-26
1.8.3 Instrumentation and Controls	1-27
1.8.4 Gas Analysis	1-27
1.8.5 Subsystem and Component Functions	1-27

TABLE OF CONTENTS, Contd

<u>Section</u>	<u>Page</u>
2 OVERALL SYSTEM SPECIFICATION.	2-1
2.1 Life Support System	2-1
2.1.1 Atmospheric Control	2-1
2.1.2 Thermal Control	2-2
2.1.3 Food, Water, and Waste Management	2-2
2.1.4 Controls and Instrumentation	2-3
2.1.5 Life Support System Test Bed	2-3
2.2 Model Criteria	2-3
2.2.1 Mission Model	2-3
2.2.2 Spacecraft Model	2-3
2.2.3 Crew Model	2-7
2.3 Performance Requirements	2-9
2.3.1 Thermal Control	2-10
2.3.2 Atmospheric Control	2-11
2.3.3 Water Management.	2-12
2.3.4 Waste Management.	2-13
2.3.5 Personal Hygiene	2-13
2.3.6 Food Management	2-13
2.3.7 Controls and Instrumentation	2-14
2.4 Human Factors Criteria	2-15
2.4.1 Crew Performance.	2-15
2.4.2 Crew Integration	2-16
2.4.3 Crew Comfort	2-16
2.4.4 Controls	2-17
2.5 Test Bed Requirements	2-17
2.5.1 Configuration.	2-17
2.5.2 Utilities	2-17
2.5.3 External Instrumentation.	2-17
2.5.4 Heat Rejection	2-18
2.5.5 Furnishings	2-18
2.6 Definition of Prototype Design	2-18
2.6.1 Design Considerations.	2-18
2.6.2 Analytical Considerations	2-19
2.6.3 Interface Designation	2-19

TABLE OF CONTENTS, Contd

<u>Section</u>	<u>Page</u>
2.6.4 Test Objectives	2-20
2.6.5 Crew Safety	2-20
2.6.6 Reliability Considerations	2-21
2.6.7 Documentation Requirements	2-22
 3 SUBSYSTEM EVALUATION	 3-1
3.1 Thermal Control	3-1
3.1.1 Thermal and Electrical Characteristics	3-1
3.1.2 Thermal Control Air Circuit	3-5
3.1.3 Thermal Control Liquid Coolant Circuit	3-8
3.1.4 Radiator Analysis and Design	3-15
3.1.5 Waste (Process) Heat Circuit	3-18
3.2 Atmospheric Control	3-20
3.2.1 CO ₂ Concentration Unit	3-20
3.2.2 CO ₂ Reduction	3-24
3.2.3 Water Electrolysis	3-53
3.2.4 Atmospheric Contaminant Control	3-60
3.2.5 Atmospheric Stores	3-77
3.3 Water Management	3-88
3.3.1 Process Techniques Considered	3-88
3.3.2 Techniques Selected	3-125
3.4 Waste Management	3-127
3.4.1 Techniques Considered	3-127
3.4.2 Waste Management Equipment	3-129
3.4.3 Urine Collection and Transport	3-129
3.4.4 Selected Techniques	3-129
3.5 Personal Hygiene	3-133
3.5.1 Techniques Considered	3-133
3.5.2 Techniques Considered	3-135
3.6 Food Management	3-135
3.6.1 Nutritional Requirements	3-135
3.6.2 Food Processing Techniques	3-136
3.6.3 Food Form and Packaging	3-137
3.6.4 Menu Selection	3-137

TABLE OF CONTENTS, Contd

<u>Section</u>	<u>Page</u>
3.7 Instrumentation and Controls	3-137
3.7.1 Operational Requirements	3-137
3.7.2 Criteria	3-138
3.7.3 Function	3-138
3.7.4 Configuration.	3-139
4 SUBSYSTEM SPECIFICATION	4-1
4.1 Thermal Control	4-1
4.1.1 Fluid Cooling and Pumping Unit	4-1
4.1.2 Fluid Heating and Pumping Unit	4-2
4.1.3 Coolant Fluid Heater	4-2
4.1.4 Air (Duct) Heater	4-2
4.1.5 Cabin Air Heat Exchanger	4-3
4.1.6 Cabin Air Temperature Control System	4-3
4.2 Atmospheric Control	4-4
4.2.1 Oxygen Recovery	4-5
4.2.2 Atmospheric Pressurization.	4-13
4.2.3 Contaminant Control	4-15
4.2.4 Ventilation and Flow	4-17
4.3 Water Management.	4-18
4.3.1 Description of Subsystem.	4-20
4.3.2 Water Utilization and Purity.	4-24
4.3.3 Subsystem Operation	4-25
4.3.4 Integration	4-30
4.4 Waste Management.	4-32
4.4.1 Waste Management Subsystem	4-34
4.5 Personal Hygiene	4-36
4.6 Food Management	4-36
4.6.1 Menu and Food Quality	4-36
4.6.2 Food Preparation Facilities	4-38
4.6.3 Food Storage	4-38
4.6.4 Weight and Volume	4-38

TABLE OF CONTENTS, Contd

<u>Section</u>		<u>Page</u>
4.7	Instrumentation and Control	4-39
4.7.1	Classification of Instrumentation and Control	4-39
4.7.2	Spacecraft System	4-39
4.7.3	Ground Control	4-41
4.7.4	Operational Requirements	4-42
4.7.5	Gas Analysis	4-45
5	PROCUREMENT SPECIFICATIONS	5-1
5.1	Summary of a Typical Specification	5-1
5.1.1	Section 1 - Scope	5-1
5.1.2	Section 2 - Applicable Documents	5-2
5.1.3	Section 3 - Requirements.	5-2
5.1.4	Section 4 - Quality Assurance Provisions	5-2
5.1.5	Section 5 - Philosophy and Criteria	5-3
5.1.6	Section 6 - Documentation	5-3
5.2	Summary of Specific Requirements	5-3
5.2.1	CO ₂ Concentration Unit	5-3
5.2.2	CO ₂ Reduction Unit.	5-5
5.2.3	Water Electrolysis Unit	5-6
5.2.4	High-Temperature Catalytic Burner	5-8
5.2.5	Waste Heat Air Evaporation Water Recovery Unit	5-9
5.2.6	Filtration Water Recovery Unit	5-11
5.2.7	Waste Management System	5-12
5.2.8	Personal Hygiene	5-14
5.2.9	Food Management	5-14
5.2.10	Cabin Air Water Separator	5-16
5.2.11	Test Support Equipment	5-17
6	FINAL DESIGN DESCRIPTION	6-1
6.1	Reliability and Quality Assurance	6-1
6.1.1	Reliability and Quality Assurance Program.	6-1
6.1.2	Quality Assurance Problems	6-1
6.2	Subsystem Designs	6-9
6.2.1	Thermal Control	6-9
6.2.2	Atmospheric Control	6-27

TABLE OF CONTENTS, Contd

<u>Section</u>		<u>Page</u>
	6.2.3 Water Management.	6-61
	6.2.4 Waste Management.	6-68
	6.2.5 Personal Hygiene	6-72
	6.2.6 Food Management	6-76
	6.2.7 Instrumentation and Controls	6-78
	6.3 Test Bed Design.	6-93
	6.3.1 Configuration	6-93
	6.3.2 Racks.	6-96
	6.3.3 Acoustics	6-98
	6.3.4 Furnishings	6-99
7	TEST PROGRAM	7-1
	7.1 Source Acceptance Inspection.	7-1
	7.2 Convair Functional Checkout	7-1
	7.3 Unit Performance Tests	7-1
	7.4 Demonstration Tests	7-2
8	TEST RESULTS AND DISCUSSION	8-1
	8.1 Thermal Control.	8-1
	8.1.1 Vendor SAI Tests	8-1
	8.1.2 Convair Functional Checkout	8-6
	8.1.3 Convair System Evaluation	8-11
	8.2 Atmospheric Control	8-23
	8.2.1 CO ₂ Concentration Unit	8-23
	8.2.2 CO ₂ Reduction Unit.	8-84
	8.2.3 Electrolysis Unit	8-101
	8.2.4 Contaminant Control	8-124
	8.3 Water Management.	8-135
	8.3.1 SAI Tests	8-135
	8.3.2 Convair Functional Checkout	8-142
	8.3.3 Performance Evaluation	8-146
	8.3.4 Final Demonstration Test	8-147
	8.4 Waste Management	8-150
	8.4.1 SAI Tests	8-150

TABLE OF CONTENTS, Contd

<u>Section</u>	<u>Page</u>
8.4.2 Convair Functional Checkout	8-151
8.4.3 Performance Evaluation	8-151
8.4.4 Final Demonstration Tests	8-156
8.5 Personal Hygiene	8-156
8.5.1 SAI Tests	8-156
8.5.2 Convair Functional Checkout	8-156
8.5.3 Performance Evaluation	8-157
8.5.4 Final Demonstration Tests	8-157
8.6 Food Management	8-157
8.6.1 SAI Tests	8-157
8.6.2 Convair Functional Checkout	8-158
8.6.3 Performance Evaluation	8-158
8.6.4 Final Demonstration Tests	8-160
8.7 Test Bed Pressurization	8-160
8.7.1 Vendor SAI Tests	8-160
8.7.2 Convair Functional Checkout	8-161
9 CONCLUSIONS AND RECOMMENDATIONS	9-1
 <u>Appendix</u>	
A CALIBRATION DATA	A-1
B DOCUMENT SUMMARY	B-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1.6-1	Process (Waste) Heat Circuit Flow Diagram	1-15
1.6-2	Liquid Coolant Circuit Flow Diagram	1-16
1.6-3	Air Circuit Flow Diagram	1-17
1.6-4	Water Management System	1-19
1.6-5	Waste Management System	1-20
3.1-1	Thermal and Electrical Requirements	3-3
3.1-2	Spacecraft Outside Surface Temperature	3-5
3.1-3	Energy Balance Summary	3-6
3.1-4	Airflow Rate Requirements	3-7
3.1-5	Performance Maps of Air Circuit Control System	3-9
3.1-6	Heat Coefficient Requirements	3-10
3.1-7	Thermal Control Air Circuit Flow Schematic	3-11
3.1-8	Heat Transport Fluid Characteristics; Laminar Pumping Power	3-13
3.1-9	Liquid Coolant (FC-75) Flow Diagram	3-14
3.1-10	Absorbed Energy Distribution Around Cylinder	3-16
3.1-11	Space Radiator Tube and Fin Configuration	3-18
3.1-12	Typical Radiator Performance	3-19
3.1-13	Process Heat (DC-331) Flow Diagram	3-21
3.2-1	CO ₂ Concentration Unit Simplified Schematic	3-23
3.2-2	Proposed Solid Amine System	3-23
3.2-3	Bosch Reaction System	3-29
3.2-4	Tapco Bosch CO ₂ Reduction System Flow Diagram	3-32
3.2-5	MRD Bosch CO ₂ Reduction System Flow Diagram	3-33
3.2-6	Sabatier Reaction System	3-36
3.2-7	MRD Sabatier CO ₂ Reduction Unit Flow Diagram	3-38
3.2-8	MRD Sabatier Reactor	3-40
3.2-9	Solid Electrolyte System	3-40
3.2-10	Recycle Gas Bleed from Bosch System Required to Remove Weight of Nitrogen Introduced	3-42
3.2-11	Recycle Gas Bleed from Bosch System Required to Remove Volume of Nitrogen Introduced	3-43
3.2-12	Oxygen Required to Burn Bosch Reactor Gases	3-46
3.2-13	Weight Comparison Between Storing Oxygen and Storing Water for Electrolysis	3-47
3.2-14	Bosch and Sabatier Weight Penalty Comparisons	3-51
3.2-15	Bosch and Sabatier System Weight Penalty Comparisons with 0.1 lb/day N ₂ Contamination	3-52
3.2-16	Reliability Comparisons for Various Configurations of the Bosch and Sabatier Systems	3-54
3.2-17	Membrane Resin Cell	3-58

LIST OF ILLUSTRATIONS (Contd)

<u>Figure</u>		<u>Page</u>
3.2-18	Double Membrane Cell	3-58
3.2-19	Wick-type Unit	3-59
3.2-20	Phosphorous Pentoxide Cell	3-59
3.2-21	Rotating Cell	3-61
3.2-22	Potassium Hydroxide Cell	3-61
3.2-23	Cabin Leakage	3-78
3.2-24	Cabin Pressure Decay	3-79
3.2-25	Cryogenic Storage Methods	3-81
3.2-26	Withdrawal Rates from Stores During a Cabin Repressurization.	3-83
3.2-27	Repressurization Thermal Input Requirement for Supercritical Storage	3-84
3.2-28	Repressurization Thermal Inout Requirement for Subcritical Storage	3-85
3.3-1	Scaling Factors for Vapor Compression Units	3-91
3.3-2	Electrodialysis - Adsorption	3-94
3.3-3	Vacuum Distillation - Pyrolysis	3-95
3.3-4	Vapor Compression	3-96
3.3-5	Waste Heat Air Evaporation	3-97
3.3-6	Waste Heat Vacuum Distillation - Adsorption	3-98
3.3-7	Waste Heat Vacuum Distillation - Pyrolysis Using Static Evaporator and Condenser	3-99
3.3-8	Waste Heat Vacuum Distillation - Pyrolysis Using Dynamic Evaporator and Condenser	3-100
3.3-9	Multifiltration System	3-101
3.3-10	Total Weight vs. Mission Duration for Urine Reclamation Process	3-102
3.3-11	Total Weight vs. Mission Duration for Water Recovery Processes	3-103
3.3-12	Total Weight vs. Mission Duration for Humidity Condensate Recovery Processes	3-104
3.3-13	Probability of Adequate Spares for Several Spares Levels vs. Parts MTBF	3-122
3.3-14	Mission Time vs. Probability of Maintaining at Least Minimum Water Recovery Requirements During Initial Year of Operation.	3-123
3.3-15	Weight Calculations, System Spares	3-124
3.3-16	System Merit Values vs. System Weight	3-125
3.4-1	Comparison of Waste Management Techniques	3-132
3.7-1	Instrumentation and Control System Configuration	3-140

LIST OF ILLUSTRATIONS (Contd)

Figure

3.2-18	Double Membrane Cell
3.2-19	Wick-type Unit
3.2-20	Phosphorous Pentoxide Cell
3.2-21	Rotating Cell
3.2-22	Potassium Hydroxide Cell
3.2-23	Cabin Leakage
3.2-24	Cabin Pressure Decay
3.2-25	Cryogenic Storage Methods
3.2-26	Withdrawal Rates from Stores During a Cabin Repressurization
3.2-27	Repressurization Thermal Input Requirement for Supercritical Storage
3.2-28	Repressurization Thermal Input Requirement for Subcritical Storage
3.3-1	Scaling Factors for Vapor Compression Units
3.3-2	Electrodialysis - Adsorption
3.3-3	Vacuum Distillation - Pyrolysis
3.3-4	Vapor Compression
3.3-5	Waste Heat Air Evaporation
3.3-6	Waste Heat Vacuum Distillation - Adsorption
3.3-7	Waste Heat Vacuum Distillation - Pyrolysis Using Static Evaporator and Condenser
3.3-8	Waste Heat Vacuum Distillation - Pyrolysis Using Dynam Evaporator and Condenser
3.3-9	Multifiltration System
3.3-10	Total Weight vs. Mission Duration for Urine Reclamation Process
3.3-11	Total Weight vs. Mission Duration for Water Recovery Processes
3.3-12	Total Weight vs. Mission Duration for Humidity Condensation Recovery Processes
3.3-13	Probability of Adequate Spares for Several Spares Levels vs. Parts MTBF
3.3-14	Mission Time vs. Probability of Maintaining at Least Minimum Water Recovery Requirements During Initial Year of Operation
3.3-15	Weight Calculations, System Spares
3.3-16	System Merit Values vs. System Weight
3.4-1	Comparison of Waste Management Techniques
3.7-1	Instrumentation and Control System Configuration

LIST OF ILLUSTRATIONS (Contd)

<u>Figure</u>		<u>Page</u>
4.2-1	Atmospheric Control System Schematic	4-6
4.2-2	CO ₂ Concentration Unit Schematic	4-8
4.2-3	CO ₂ Reduction Unit Inflows and Outflows	4-10
4.2-4	Water Electrolysis Unit Inflow and Outflow Schematic	4-12
4.2-5	LSS Test Bed Pressure Regulation Schematic.	4-14
4.2-6	Contaminant Control System Flow Schematic	4-16
4.2-7	System Static Pressure Profile	4-19
4.3-1	Integrated Water Management System Revised Schematic	4-21
4.4-1	Waste Management Schematic	4-35
4.5-1	Personal Hygiene System Schematic	4-37
6.1-1	Reliability and QA Program Development Items	6-2
6.1-2	Project Quality Assurance Activities.	6-3
6.1-3	SAI Forms	6-4
6.1-4	Failure Rate Improvement During Contractor Tasks	6-8
6.2-1	Installed Thermal Control Air Circuit Flow Schematic	6-10
6.2-2	Cabin Air Heat Exchanger (System A)	6-11
6.2-3	Liquid Coolant (Propylene Glycol) Circuit Flow Schematic	6-14
6.2-4	Fluid Cooling and Pumping Unit Flow Schematic	6-16
6.2-5	Coolant Fluid Heater	6-17
6.2-6	Process Heat (DC-331) Circuit Flow Schematic	6-18
6.2-7	Fluid Heating and Pumping Unit Flow Schematic	6-21
6.2-8	Air Current Configuration	6-22
6.2-9	Air Deflection	6-22
6.2-10	Capillary Forces	6-23
6.2-11	Cabin Air/Water Separator Schematic	6-24
6.2-12	Chevron Packing	6-25
6.2-13	TRW Pump Capacity	6-26
6.2-14	CO ₂ Concentration Unit	6-28
6.2-15	CO ₂ Concentration Unit Control	6-31
6.2-16	CO ₂ Concentration Unit Zeolite Canister	6-32
6.2-17	CO ₂ Concentration Unit Right Side View.	6-33
6.2-18	CO ₂ Concentration Unit Left Side View	6-34
6.2-19	CO ₂ Concentration Unit Control Panel Door	6-35
6.2-20	CO ₂ Concentration Unit Control Panel Interior	6-36
6.2-21	CO ₂ Reduction Unit Flow Schematic	6-38
6.2-22	CO ₂ Reduction Unit Installation	6-39
6.2-23	CO ₂ Reduction Unit Low Temperature Package	6-40
6.2-24	CO ₂ Reduction Unit Valve Display Panel	6-41
6.2-25	CO ₂ Reduction Unit High Temperature Package	6-42

LIST OF ILLUSTRATIONS (Contd)

<u>Figure</u>		<u>Page</u>
6.2-26	CO ₂ Reduction Unit Bosch Reactor Catalyst Plates	6-43
6.2-27	CO ₂ Reduction Unit Control Panel.	6-44
6.2-28	Electrolysis Unit Flow Schematic.	6-47
6.2-29	Underside of Electrolysis Unit.	6-49
6.2-30	Electrolysis Unit Left Side	6-50
6.2-31	Electrolysis Unit Right Side.	6-51
6.2-32	Electrolysis Unit Performance Panel	6-51
6.2-33	Catalytic Burner Assembly	6-57
6.2-34	Catalytic Burner	6-60
6.2-35	Catalytic Burner Control Panel	6-62
6.2-36	Water Management System Schematic Normal Mode.	6-63
6.2-37	Evaporation Unit Schematic.	6-64
6.2-38	Back View of Water Management Subsystem	6-65
6.2-39	Multifilter Unit	6-65
6.2-40	Multifilter Unit Installation	6-66
6.2-41	Waste Management System Schematic	6-69
6.2-42	Waste Management Assembly	6-70
6.2-43	Personal Hygiene Panel	6-73
6.2-44	Sponge Squeezer Circuit.	6-74
6.2-45	Hygiene Water Heating System Schematic	6-75
6.2-46	Meal Preparation	6-77
6.2-47	Food Management Fluid Circuit	6-78
6.2-48	CO ₂ Concentration Panel	6-79
6.2-49	CO ₂ Reduction Panel	6-80
6.2-50	Water Electrolysis Panel	6-81
6.2-51	Air/Water Evaporation Process Panel	6-82
6.2-52	Operational Status Panel.	6-83
6.2-53	Ground Control Console	6-84
6.2-54	Typical 115V, 400 CPS Main Power Control Circuitry	6-86
6.2-55	Typical Main 28VDC Control Circuit.	6-87
6.2-56	Typical Warning Light and Alarm Circuit	6-88
6.2-57	Loss of Power Warning Circuits	6-89
6.2-58	Gas Sampling Circuit (Typical)	6-91
6.3-1	LSS Test Bed	6-94
6.3-2	LSS Test Bed Interior	6-95
6.3-3	LSS Test Bed Air Lock	6-97
6.3-4	LSS Test Bed Sleeping Area.	6-100

LIST OF ILLUSTRATIONS. (Contd)

<u>Figure</u>		<u>Page</u>
8.1-1	Fluid Cooling and Pumping Unit	8-3
8.1-2	Fluid Heating and Pumping Unit	8-5
8.1-3	Coolant Fluid Heater Heating Capacity	8-14
8.1-4	Coolant Fluid (Propylene Glycol) Circuit Flow Distribution	8-17
8.1-5	Process Heat (DC-331) Circuit Flow Distribution	8-22
8.2-1	CO ₂ Concentration Unit Preliminary Canister Tests.	8-26
8.2-2	CO ₂ Concentration Unit Canister Pressure History (1 March 1965)	8-31
8.2-3	CO ₂ Concentration Unit Canister Pressure History (11 May 1965)	8-32
8.2-4	CO ₂ Concentration Unit Repeat Cycle Sequence.	8-34
8.2-5	CO ₂ Concentration Unit Timer Sequence as Received at Convair.	8-35
8.2-6	CO ₂ Concentration Unit Preliminary Timer Sequence	8-36
8.2-7	CO ₂ Concentration Unit Final Timer Sequence	8-37
8.2-8	CO ₂ Concentration Unit Purity	8-49
8.2-9	CO ₂ Concentration Unit Air Flow	8-50
8.2-10	CO ₂ Concentration Unit CO ₂ Rates	8-51
8.2-11	CO ₂ Concentration Unit Accumulator Pressure History	8-52
8.2-12	CO ₂ Concentration Unit Fluid Temperature History; 10-psia Test	8-58
8.2-13	CO ₂ Concentration Unit Air Temperature History; 10-psia Test	8-59
8.2-14	CO ₂ Concentration Unit Adsorbing Zeolite Bed Air Temperature History; 10-psia Test	8-60
8.2-15	Process Heat and Coolant Fluid Flow	8-61
8.2-16	CO ₂ Inlet and Outlet Concentration and Air Flow	8-62
8.2-17	Accumulator - Pressure History	8-65
8.2-18	Vacuum Desorption Test	8-70
8.2-19	CO ₂ Concentration Unit 10 psia Vacuum Desorption Test	8-71
8.2-20	CO ₂ Concentration Unit Thermal Desorption Purity Test	8-73
8.2-21	CO ₂ Concentration Unit Accumulator Purity vs. Purge Time	8-74
8.2-22	CO ₂ Concentration Unit Thermal Desorption Mode Test	8-78
8.2-23	CO ₂ Concentration Unit \approx 10 psia Thermal Desorption Mode Test Temperatures	8-79
8.2-24	CO ₂ Concentration Unit Demonstration Test.	8-81
8.2-25	CO ₂ Concentration Unit Flow Rate	8-85
8.2-26	CO ₂ Concentration Unit Temperatures	8-86
8.2-27	Cabin and Zeolite Bed CO ₂ Concentration.	8-87
8.2-28	CO ₂ Concentration Unit Moisture Content.	8-88
8.2-29	Laboratory and Zeolite Bed CO ₂ Concentration	8-89

LIST OF ILLUSTRATIONS (Contd)

<u>Figure</u>		<u>Page</u>
8.2-30	SAI Test Data, Electrolysis Module A	8-104
8.2-31	SAI Test Data, Electrolysis Module B	8-105
8.2-32	SAI Test Data, Electrolysis Module C	8-106
8.2-33	SAI Test Data, Rebuilt Module A	8-107
8.2-34	N ₂ Flow vs. Pressure Drop, Electrolysis Module B Coolant Test. .	8-111
8.2-35	Pressure Drop vs. Water Flow, Electrolysis Module B Coolant Test	8-112
8.2-36	Electrolysis Module B Glycol Flow vs. Pressure Drop	8-113
8.2-37	Electrolysis Unit Coolant Flow Calibration	8-114
8.2-38	Temperature Control Test, Module A	8-115
8.2-39	Temperature Control Test, Three Modules, All Valves Open . . .	8-116
8.2-40	Characteristics of Coolant Pressure Regulator	8-118
8.2-41	Characteristics of Gas Pressure Regulators at Two Set Points . .	8-119
8.2-42	Specific Gravity of Sulfuric Acid Solutions	8-123
8.2-43	Catalytic Burner Heating Characteristic, Heater Mode Normal . .	8-127
8.2-44	Catalytic Burner Heating Characteristic, High Position	8-128
8.2-45	Catalytic Burner Heating Characteristic, Unit S/N 001	8-131
8.2-46	Catalytic Burner Heating Characteristic, Unit S/N 002	8-132
8.2-47	Catalytic Burner Temperature Profiles	8-136
8.3-1	Air Evaporation Unit, Heat Balance = 10 psia, Cooling Fluid = 83° F	8-138
8.3-2	Air Evaporation Unit, Heat Balance = 10 psia, Cooling Fluid = 55° F	8-139
8.3-3	Air Evaporation Unit, Heat Balance = Sea Level, Cooling Fluid = 83° F	8-140
8.3-4	Water Recovery Unit No. 2 Test Data	8-149
8.4-1	Vacuum Leakup Test	8-152
8.4-2	Dryer Circuit Temperature Functional Checkout	8-153
8.4-3	Feces Dryer Temperature History	8-154
8.4-4	Feces Dryer, Specimen Weight Loss vs. Time	8-155
8.6-1	Food Management Water Heater Water Temperatures	8-159

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1.3-I	Atmospheric Quantities.	1-3
1.3-II	Heat Loads from Simulated Electronic Equipment	1-4
1.3-III	Average Metabolic Balance per Man-Day	1-6
1.3-IV	Daily Activity Metabolic Criteria	1-6
1.4-I	Water Balance (Basis: 1 Man-Day)	1-8
1.4-II	Urine System Weights	1-9
1.4-III	Water Recovery/Urine Processing - LSS Rating	1-10
1.4-IV	Subsystem Composition and Sizing	1-11
1.4-V	Integrated Water Reclamation System Weights	1-12
1.4-VI	Integrated Water Reclamation System Ratings	1-13
1.6-I	System Weight, Volume, and Power	1-23
2.2-I	Mission Model	2-4
2.2-II	Spacecraft Atmospheric Quantities	2-5
2.2-III	Heat Rejection from On-Board Equipment	2-6
2.2-IV	Metabolic Criteria per Man	2-7
2.2-V	Daily Activity Metabolic Criteria	2-8
2.2-VI	Emergency Metabolic Criteria (One Hour)	2-8
2.3-I	Laboratory Area Criteria	2-9
2.3-II	Living Area Criteria	2-10
2.3-III	Cabin Atmosphere Specifications	2-11
3.2-I	CO ₂ Concentration Techniques	3-25
3.2-II	Reliability Problem Summary Chart	3-26
3.2-III	Rating Chart, CO ₂ Concentration Unit.	3-27
3.2-IV	Estimated CO ₂ Reduction Subsystem Characteristics. . .	3-28
3.2-V	Tapco Bosch System Weight, Volume, and Power Breakdown	3-31
3.2-VI	MRD Bosch System Weight and Power Breakdown	3-35
3.2-VII	MRD Sabatier System Weight and Power Breakdown . . .	3-37
3.2-VIII	Bosch and Sabatier CO ₂ Reduction System Adjusted Weights	3-48
3.2-IX	Rating Chart, CO ₂ Reduction Unit	3-55
3.2-X	Sources of Contamination	3-63
3.2-XI	Compounds Quantitatively Identified in Submarine Atmospheres	3-65
3.2-XII	Compounds Qualitatively Identified in Trace Amounts in Submarine Atmospheres	3-66
3.2-XIII	Trace Contaminants Identified or Tentatively Identified in Space Cabin Simulator Atmosphere	3-67

LIST OF TABLES (Contd)

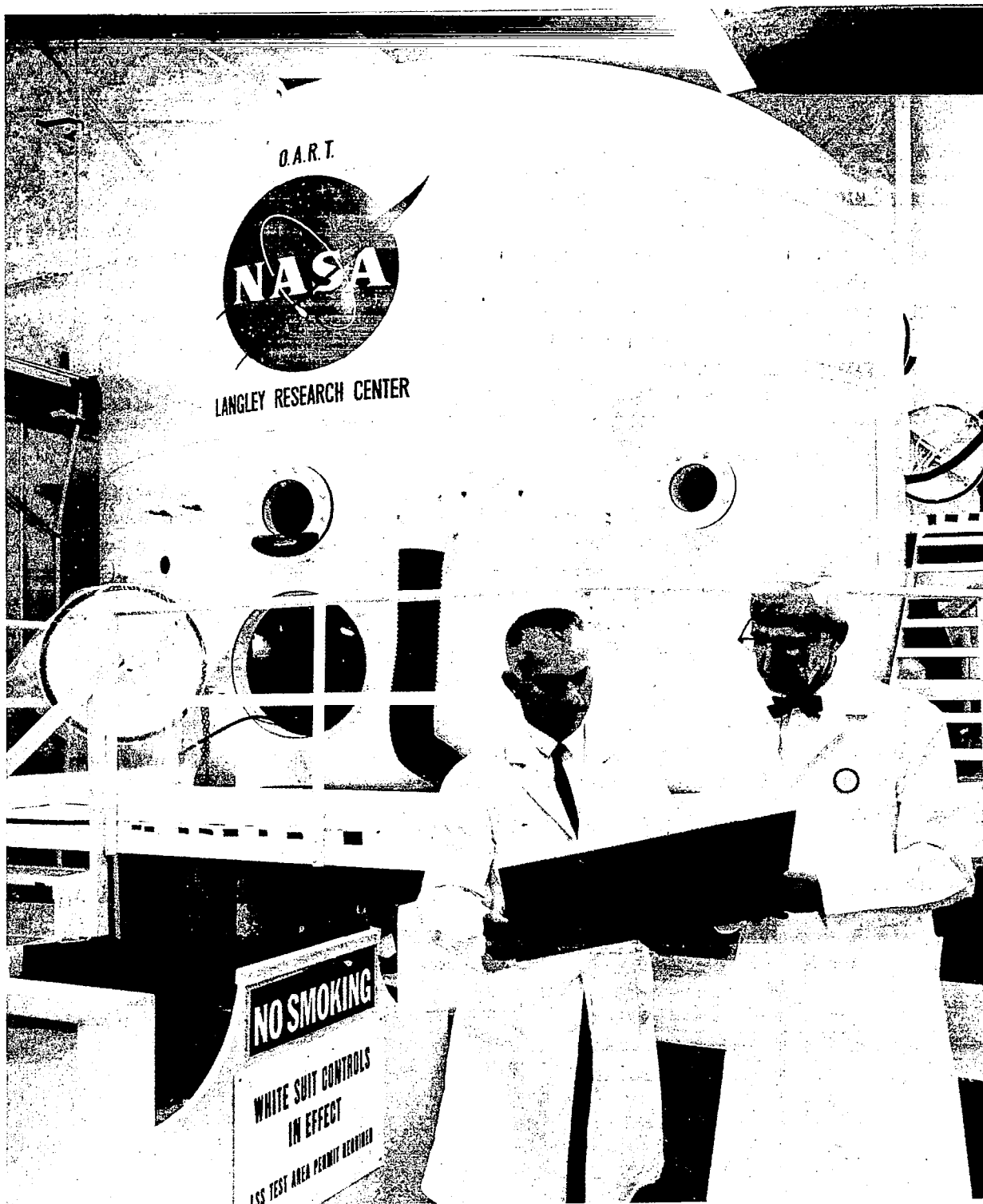
<u>Table</u>		<u>Page</u>
3.2-XIV	Atmospheric Contaminants Recovered from AMRL Environmental Test Chamber.	3-69
3.2-XV	A Compilation of All Contaminants Identified in the Atmospheres of Mercury Spacecraft	3-70
3.2-XVI	Total Waste Accumulation per Man-Day	3-73
3.2-XVII	Recommended Maximal Acceptable Concentration for Continuous Exposure	3-75
3.2-XVIII	Weight and Volume Comparison for Atmospheric Storage Containers	3-87
3.3-I	Water Balance (Basis: 1 Man-Day)	3-90
3.3-II	Summary of Candidate Water Recovery Techniques Rejected in First Iteration	3-105
3.3-III	Summary of Candidate Water Recovery Techniques Accepted in First Iteration	3-107
3.3-IV	Estimated Weights of Urine Recovery Systems	3-109
3.3-V	Estimated Weights of Wash Water Recovery Systems	3-110
3.3-VI	Estimated Weights of Humidity Condensate Recovery Systems	3-111
3.3-VII	Reliability Appraisals for Eight Approaches to Waste Water Processing (H ₂ O Recovery) Systems	3-112
3.3-VIII	LSS Ratings of Water Recovery/Urine Processing	3-113
3.3-IX	LSS Ratings of Water Recovery/Wash/Processing Systems	3-114
3.3-X	LSS Ratings of Water Recovery/Humidity-Condensate/ Processing Systems	3-115
3.3-XI	Subsystem Composition and Sizing	3-117
3.3-XII	Minimum Continuous Level Capacity	3-118
3.3-XIII	Total Water Reclamation System Weights and Power	3-120
3.3-XIV	Mean Time Between Failures	3-121
3.3-XV	Integrated Water Reclamation System Rating Chart	3-126
3.4-I	Feces Treatment Techniques	3-128
3.4-II	Feces Collection and Transport Techniques	3-130
3.4-III	Ranking Chart, Waste Management Equipment Combinations	3-131
3.5-I	Body Cleansing Techniques	3-134
4.3-I	Emergency Water Balance	4-30
4.3-II	Estimated Heating and Cooling Requirements, Water Management Subsystem	4-31
4.3-III	Start-up Water Requirements	4-33

LIST OF TABLES (Contd)

<u>Table</u>		<u>Page</u>
4.7-I	Functional Requirements	4-40
4.7-II	Water Electrolysis Failure and Effects Analysis	4-43
4.7-III	Gas Analysis Requirements	4-46
6.1-I	Summary of Equipment Failures During System Test	6-7
6.2-I	Electrolysis Unit Valve Functions	6-48
6.2-II	Test Program Gas-Analysis Requirements	6-42
8.1-I	Cabin Air/Water Separator Test Results	8-10
8.1-II	Performance Characteristics, Fluid-Cooling and Pumping Unit, 13 July 1965	8-16
8.1-III	Pressure Drop for 1000 lb/hr Fluid-Flow Rate	8-18
8.1-IV	Performance Characteristics, Fluid-Heating and Pumping Unit, 13 July 1965	8-20
8.1-V	Pressure Drops Introduced by Individual Components.	8-23
8.2-I	Provision of Paragraph 6.0, Acceptance Test Plan Supplement 1	8-24
8.2-II	CO ₂ Concentration Unit Run Summary	8-30
8.2-III	CO ₂ Concentration Unit Accumulator Volume Check	8-40
8.2-IV	CO ₂ Concentration Unit Zeolite Canister Volume Check	8-42
8.2-V	CO ₂ Concentration Unit Sea-Level Test Data	8-45
8.2-VI	CO ₂ Concentration Unit Sea-Level Test; CO ₂ Volume vs. Time	8-48
8.2-VII	CO ₂ Concentration Unit 10-psia Test Data	8-54
8.2-VIII	CO ₂ Concentration Unit 10-psia Test; CO ₂ Volume vs. Time	8-57
8.2-IX	10-psia Vacuum Desorption Test Data	8-66
8.2-X	10-psia Vacuum Desorption Test; CO ₂ Volume vs. Time.	8-69
8.2-XI	NASA 10-psia Demonstration Thermal Desorption Run Test Data	8-76
8.2-XII	Final 10-psia Thermal Desorption Test; CO ₂ Volume vs. Time	8-77
8.2-XIII	NASA 10-psia Demonstration Vacuum Desorption Run Test Data	8-83
8.2-XIV	Final 10-psia Vacuum Desorption Test; CO ₂ Volume vs. Time	8-84
8.2-XV	Typical SAI Test Data, CO ₂ Reduction Unit, Bosch Mode.	8-90
8.2-XVI	Typical SAI Test Data, CO ₂ Reduction Unit, Sabatier Mode	8-91
8.2-XVII	Typical Functional Checkout Data, CO ₂ Reduction Unit, Bosch Mode.	8-92
8.2-XVIII	Typical Functional Checkout Data, CO ₂ Reduction Unit, Sabatier Mode	8-93

LIST OF TABLES (Contd)

<u>Table</u>		<u>Page</u>
8.2-XIX	Typical Demonstration Test Data, CO ₂ Reduction Unit, Bosch Mode	8-99
8.2-XX	Typical Demonstration Test Data, CO ₂ Reduction Unit, Sabatier Mode	8-101
8.2-XXI	Electrolysis Unit Test Data	8-110
8.2-XXII	Typical Final Data on Electrolysis Unit	8-120
8.2-XXIII	Catalytic Burner Heating Tests	8-133
8.2-XXIV	Catalytic Burner Final Demonstration Test Data	8-137
8.3-I	Processed Water (Urine) Analysis	8-141
8.3-II	Humidity Condensate	8-143
8.3-III	Water Management System; Water Recovery Units	8-148



Life Support System Test Bed

SECTION 1

INTRODUCTION AND SUMMARY

This report summarizes a comprehensive two-year program to develop a prototype physical-chemical life-support system for space flights of extended time periods, providing reclamation and reuse of water and oxygen for a four-man crew and maintaining a safe, comfortable atmosphere in a test chamber which simulates a spacecraft. The program was accomplished by the Life Sciences Department of the Convair Division of the General Dynamics Corporation for the NASA Langley Research Center. It included engineering and optimization studies to select the most promising fundamental processes, establish configurations of minimum weight and power consistent with reliability, and test the operation and performance of the integrated system.

1.1 PROGRAM OBJECTIVES

Depth, scope, and direction were provided by the following program objectives. The prototype life support system developed under this program meets these objectives and will provide a technological base for continued progress toward systems for space flights of extended time periods.

- a. Develop a fully integrated system in which process rates, power requirements, and heat rejection are compatible with realistic mission, crew, and spacecraft models.
- b. Design for compatibility with zero-g operation so the prototype systems differ from flight-type systems only with respect to weight, bulk, and detailed design.
- c. Achieve high reliability and safety based upon the optimum utilization of crew capabilities for operation and maintenance.
- d. Obtain minimum weights and power by efficient use of the waste heat of a simulated isotope power supply.
- e. Achieve a tangible and practical advancement in the state of the art.
- f. Demonstrate the operation and performance of the integrated system by testing at design conditions.
- g. Deliver the prototype systems, installed in the spacecraft test hull, to the NASA Langley Research Center for use in a research test program.

1.2 SYSTEM REQUIREMENTS

The system provides for all the needs of four men when resupplied at 90-day intervals with freeze-dried food, atmospheric stores for makeup of cabin leakage,

equipment spares, and other expendables. Although the equipment is inherently stable or automatically controlled, man is integrated into the system for start-up and shut-down, monitoring and manual override when necessary, and maintenance. The system has an operating lifetime of one year when provided with resupply and maintenance.

The following functional requirements of the life-support system and spacecraft test hull are dictated by the regenerative nature of the system and the requirement for maintaining a long-term habitable environment.

- a. Atmospheric Control. Cabin pressurization, circulation of air, processing CO₂ to recover the oxygen, and removal of contaminants to control the composition of the cabin air.
- b. Thermal Control. Regulation of compartment temperatures and heat flux in all components except a simulated isotope power supply.
- c. Food, Water, and Waste Management. Storage and reconstitution of food, reclamation, storage and distribution of water, and collection, processing, and storage of body wastes and sanitary supplies.
- d. Controls and Instrumentation. Sensing and display of physical data for operation and control of equipment and alarms to warn of malfunction.
- e. Test Integration. Means for integrated testing, provided by a spacecraft cabin test hull, with laboratory and living space appropriate to the mission.

1.3 MODEL CRITERIA

1.3.1 MISSION MODEL. Mission simulation presumes the spacecraft to be an earth-orbiting scientific satellite. The following definition was established primarily for calculating the thermal radiation exchange with such an environment.

Operational Period	1967
Mission Duration	One year
Mission Objectives	Scientific experiments
Resupply Capability	Once each 90 days
Orbital Elements	Zero eccentricity 250 n. mi. altitude 30-degree orbit inclination to the solar vector
Vehicle Attitude	No rotation; cylindrical axis to be normal to the solar vector
Gravity	Zero-g

1.3.2 SPACECRAFT MODEL. The cabin test hull is a cylinder 220 inches in diameter and 215 inches long, erected with the axis vertical, and equipped with an air lock, emergency hatches, viewing ports, interface panel, and a ladder between the equipment laboratory on the lower deck and the living module on the upper deck.

Atmospheric quantities were based upon the data in Table 1.3-I.

Table 1.3-I. Atmospheric Quantities

Volume, ft ³	Living Module	1755
	Laboratory	2305
	Air Lock	90
	Total	4150
Leakage Rates, lb/mo	Living Module	14.1
	Laboratory	18.6
	Air Lock	0.8
	Total	33.5
Air Lock Operation	5 cycles/90 days	
Spacecraft Repressurization	Once/90 days	

Optimization of thermal control was based upon a radiator that is integral to the cylindrical surface of the vehicle, does not see the vehicle, and is of fin-tube construction. Heat loads from the (simulated) electronic equipment were as shown in Table 1.3-II.

Optimization of system weight was based upon the following tradeoff criteria.

Power Penalty	290 lb/kw
Maximum Power	5 kw (2 to 2.5 kw for the life-support system)
Heat Rejection Penalty	Sensible 0.01 lb per Btu/hour Latent 28 lb per lb of water/hour

Only tubes and fluid of the radiators are chargeable to the life-support system, since the fin material is part of the spacecraft structure.

Table 1.3-II. Heat Loads from Simulated Electronic Equipment

	<u>Power Level (watts)</u>		
	<u>Continuous</u>	<u>Intermittent</u>	<u>Total</u>
Tracking	-	84	84
Intercommunication	10	-	10
Communication and Data Processing	266	798	1064
Attitude Control	160	-	160
Inertia Wheels	300	-	300
TV	231	-	231
Rendezvous	-	300**	300
Displays	10	-	10
Lighting	150	-	150
Experiments	1000	-	1000
Total	2127	882*	3309

* Six minutes duration, 36 times per day.

** Two hours duration, once per 90 days.

The quality of electric power is:

110 vac \pm 1%

400 cps \pm 1%

28 vdc \pm 1%

1.3.3 CREW MODEL. The normal crew is four, two each in the living module and the laboratory. Each module must have capability for all four men for at least four days. A capability for six men (four normal crew plus two from ferry vehicle) is required for three hours once every 90 days. This requirement is not to be concurrent with system failure in one module.

A crew distribution of all four in one module is considered an emergency condition, except for brief periods as a matter of convenience to the crew.

A crew distribution of three men in either module and one in the other is considered to establish the occupancy range within which the system shall maintain an environment continuously within nominal performance specifications.

System design is based upon the following data.

a. Physical Characteristics

Size and Weight	Average 55th percentile Range 30th - 90th percentile
Sex	Male
Age	Average 37

b. Metabolic Activity (zero-g)

Normal Duties, Eight Hours	135% BMR
Off Duty, Six Hours	100% BMR
Exercise, Two Hours	600% BMR (two periods, 1 hour each)
Rest, Eight Hours	90% BMR
Average for 24 Hours	150% BMR

c. Average Metabolic Balance per Man-Day. (See Table 1.3-III.)

d. Daily Activity Metabolic Criteria. (See Table 1.3-IV.)

e. Emergency Criteria for One Hour

Two men at	150% BMR
One man at	500% BMR
One man at	1000% BMR
Average for crew	450% BMR
O ₂ Uptake	0.935 lb
CO ₂ Output	1.16 lb
H ₂ O Evaporation (Respiration and Perspiration)	3.70 lb
Metabolic Heat	5556 Btu

Table 1.3-III. Average Metabolic Balance per Man-Day

	Maximum	Minimum	Design Point
O ₂ Uptake, lb	1.87*		1.87
CO ₂ Output, lb	2.32*		2.32
Food, Ashless, Dry Basis, lb	1.38		1.38
Water of Oxidation, lb		0.72	0.72
Water Allowance, lb	7.72	6.17	7.72
Urine Water, lb	4.13	2.20	4.13
Fecal Water, lb	0.33	0.22	0.33
Urine and Fecal Solids, lb			0.22
Evaporative Water Loss (Respiration and Perspiration), lb	5.90	2.54	5.90
Latent Heat, Btu	6191	2659	6191
Sensible Heat, Btu	8453**	4921	8453**

* These are design values that do not represent concurrent O₂ consumption and CO₂ output. Therefore, they do not represent a specific respiratory quotient.

** Does not occur concurrently with maximum latent heat. Sum of sensible and latent is constant at 11,112 Btu/man-day.

Table 1.3-IV. Daily Activity Metabolic Criteria

ACTIVITY	TIME, (Hours)	RATE, (% BMR)	POUNDS PER MAN-HOUR		
			O ₂ UPTAKE	CO ₂ OUTPUT	H ₂ O EVAPORATION
Normal Duties	8	135	0.070	0.087	0.221
Off Duty	6	100	0.052	0.0645	0.164
Exercise	2	600	0.312	0.3867	0.984
Rest	8	90	0.047	0.058	0.1475
Average		150	0.078	0.0967	0.246

1.4 TRADEOFF TECHNIQUES

The tradeoff studies used to select, size, and integrate the life-support system for the minimum weight penalty consistent with mission requirements are best illustrated by reviewing the studies for a specific element of the system, such as water reclamation.

The waste waters involved are urine, used wash water, and condensate from the main cabin dehumidifier. Since reclamation of water from urine is the most difficult, any process adequate for urine will also suffice for used wash water or humidity condensate. The water balance per man-day is shown in Table 1.4-I.

1.4.1 CANDIDATE SYSTEMS. The first step in evaluation was to discard processes that were inappropriate because of insufficient development or technical disadvantage. Freeze crystallization, for example, requires the removal of relatively pure ice crystals from impure mother liquid; recovered water would have to be recycled several times to achieve a significant yield of potable water. Eighteen processes were considered and discarded for similar reasons. The following processes were retained as candidate systems for urine recovery.

Electrodialysis Adsorption

Vacuum Distillation-Pyrolysis

Vapor Compression-Adsorption

Waste Heat Air Evaporation-Adsorption

Waste Heat Vacuum Distillation-Adsorption

Waste Heat Vacuum Distillation-Pyrolysis

1.4.2 URINE SYSTEM. The second step in evaluation was to establish the total weight penalty for each process when used for urine only. Power and heat rejection were converted to weight penalties and added to the flight hardware weight and expendables for the 90-day resupply period. The results are given in Table 1.4-II.

1.4.3 URINE SYSTEM RATINGS. The third step in evaluation was to establish a relative rating for each candidate system, based on a comprehensive appraisal of reliability, confidence, maintainability, and safety, as well as weight and power. The results are shown in Table 1.4-III.

1.4.4 WASH WATER SYSTEM. All the systems described for urine water reclamation are applicable to the recovery of wash water and would weigh the same for a wash water allowance of 13.2 lb/day. A multifiltration unit specifically designed for wash water would operate on 10 watts and have a total weight of 40.2 pounds. The fourth step in evaluation was to devise weight-rating tables for the wash water system, as was done for the urine systems. The most promising technique was found to be multifiltration.

Table 1.4-I. Water Balance (Basis: 1 Man-day)

WATER TO AND FROM ASTRONAUT (lb)			
<u>Consumed and Produced</u>		<u>Waste</u>	
In food	0.23	Urine	3.30
For drinking & food preparation	7.65	Fecal water (discarded)	0.25
Metabolically produced	<u>0.72</u>	Discarded in food	0.16
Subtotal	8.60	Humidity condensate	<u>4.89</u>
Wash water	3.30	Subtotal	8.60
		Used wash water	<u>3.30</u>
TOTAL	11.90 lb	TOTAL	11.90 lb

RECOVERED WATER FOR REUSE (lb)

<u>Amount Recovered</u>		<u>Use of Recovered Water</u>	
From urine	0.95 (3.30) = 3.13	For drinking & food preparation	7.65
From condensate	0.99 (4.89) = 4.84	For washing	3.30
From wash water	0.97 (3.30) = 3.20	For electrolysis	2.10
From Bosch reactor	1.90	Excess	<u>0.02</u>
TOTAL	13.07 lb	TOTAL	13.07 lb

1.4.5 CONDENSATE SYSTEM. Since humidity condensate has the lowest level of contamination of the waste liquids, the urine recovery systems are applicable. Hardware weights and power and heat rejection penalties are higher because of the greater process rate, 19.6 lb/day. The expendable weight is lower, however, because of the relatively higher purity of the condensate. The fifth step in evaluation was to prepare weight-rating tables for the condensate systems. The most advantageous technique was again found to be multifiltration.

1.4.6. INTEGRATED WATER RECOVERY SYSTEM. Several combinations of various-sized configurations were studied. The final selection was based on the six configurations listed in Table 1.4-IV, each operating as a candidate integrated water-reclamation system. System weights are given in Table 1.4-V.

Table 1.4-II. Urine System Weights

SYSTEM	POWER (watts)	HEAT REJECTION (Btu/hr)	TOTAL* WEIGHT (lb)
Electric			
Electrodialysis Adsorpton	50.6		187.4
Vacuum Distillation-Pyrolysis	321	1097	144.3
Vapor Compression-Adsorption	44	150	79.2
Waste Heat			
Air Evaporation-Adsorption	39	1414	97.4
Vacuum Distillation-Adsorption	35	970	92.7
Vacuum Distillation-Pyrolysis	106	1212	93.7

*Includes power and heat rejection penalties and expendables for 90 days.

1.4.7 RATING THE INTEGRATED SYSTEMS. When reliability and maintainability are included in the appraisal of the integrated water recovery systems, the highest rating is achieved by combination E, two air evaporation units. (See Table 1.4-VI.) Each unit is sized to process the daily output of urine plus condensate, but in normal use, one unit will always process only urine and the other will process condensate plus used wash water.

Table 1.4-III. LSS Rating of Water Recovery/Urine Processing Systems

TRADEOFF PARAMETER	RELATIVE SENSITIVITY (S _R) OF PARAMETER (H ₂ O RECOVERY)	RELATIVE RATING						
		ELECTRO- DIALYSIS	ELECTRICAL VACUUM DISTILLATION PYROLYSIS	VAPOR COMPRESSION ADSORPTION	WH AIR EVAPORATION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM DISTILLATION PYROLYSIS (STATIC)	WH VACUUM DISTILLATION PYROLYSIS (DYNAMIC)
I. FIRST-ORDER PROPERTIES								
A Confidence (Degree of development and performance margins)	22	15.75	11.70	19.20	18.25	17.10	11.70	17.40
B Contribution to advance- ment of the state of the art	3	2.7	2.4	2.1	2.7	2.25	2.7	2.1
First-Order Total	25	18.45	14.10	21.30	20.95	19.35	14.40	19.50
II. SECOND-ORDER PROPERTIES								
A Weight								
1. Installed hardware and heat rejection	7	6.3	5.6	4.9	3.9	4.2	4.2	3.9
2. Resupply	8	2.4	7.2	6.4	6.4	6.4	7.2	7.2
Subtotal	15	8.7	12.8	11.3	10.3	10.6	11.4	11.1
B Power								
1. Peak	6	4.8	1.2	5.1	5.4	5.4	3.6	3.0
2. Average	12	10.8	2.4	10.2	10.8	10.8	7.2	6.0
Subtotal	18	15.6	3.6	15.3	16.2	16.2	10.8	9.0
C Volume								
2	2	1.2	1.6	1.6	1.2	1.6	1.6	1.2
D Reliability								
1. Repairability	5	2.5	4.0	3.5	3.5	3.5	3.5	2.5
2. Simplicity								
a. Controls	4	2.0	2.8	1.6	3.2	2.8	2.8	2.0
b. Basic Functions	3	1.2	2.1	1.8	2.4	1.8	2.1	1.8
3. Independence of failures	4	2.0	2.8	3.2	2.8	2.8	2.8	2.8
4. Process controllability	4	2.4	2.8	2.0	2.8	2.4	2.8	2.4
Subtotal	20	10.1	14.5	12.1	14.7	13.3	14.0	11.5
E Maintainability								
1. Ease of service	1	0.6	0.8	0.8	0.7	0.7	0.7	0.6
2. Frequency of service	1	0.6	0.7	0.5	0.6	0.6	0.7	0.6
3. Manhour demands	2	1.0	1.6	1.2	1.2	1.0	1.6	1.4
4. Error potential	3	1.2	2.1	1.2	1.8	2.1	2.1	2.1
5. Crew exposure to injury or illness	3	1.8	2.1	2.4	2.1	2.1	2.4	2.1
Subtotal	10	5.2	7.3	6.1	6.4	6.5	7.5	6.8
F Safety (Hazard Avoidance)								
1. Fire	2	1.4	1.2	1.4	1.6	1.6	1.4	1.4
2. Explosion	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9
3. Toxicity	2	1.2	1.6	1.2	1.2	1.2	1.6	1.2
4. Contamination buildup	3	1.8	2.1	2.1	2.4	2.1	2.1	2.1
5. Burn or shock	2	1.6	1.0	1.2	1.4	1.4	1.2	1.4
Subtotal	10	6.9	6.8	6.8	7.5	7.2	7.2	7.0
Second-Order Total	75	47.70	46.60	53.20	55.30	55.40	52.50	46.60
Grand Totals*	100	66.15	60.70	74.50	77.25	74.75	66.90	66.10

* Total of first- and second-order properties.

Table 1.4-IV. Subsystem Composition and Sizing

DESIGNATION	COMPOSITION
A	Three air evaporation units, each sized to process either urine, wash water, or condensate.
B	Two air evaporation units, each sized to handle urine and one multifiltration unit sized to handle condensate flow and wash water contaminants.
C	One air evaporation unit sized for urine and two multifiltration units each sized for condensate flow and wash water contaminants.
D	One air evaporation unit sized for urine and condensate flow (simultaneously) and one multifiltration unit sized for wash water.
E	Two air evaporation units, each sized to process the urine and condensate flow simultaneously.
F	One air evaporation unit sized to process urine, wash water, and condensate flows simultaneously.

Table 1.4-V. Integrated Water Reclamation System Weights

DESIGNATION	WEIGHT (lb)*				TOTAL (1 year)	POWER (watts)
	HEAT REJECTION**					
	HARDWARE	PENALTY	EXPENDABLES	SPARES		
A-3 Evaporation Units	93.3	94.8	152.0	138.0	478	174
B-2 Evaporation Units	51.4	53.8	148.0	104.0	357	78
1 Filter	6.0	0.3	60.2	37.2	104	10
Subtotal	57.4	54.1	208.2	141.2	461	88
C-1 Evaporation Units	25.7	26.9	134.0	77.0	264	39
2 Filters	12.0	0.6	164.2	51.0	228	20
Subtotal	37.7	27.5	298.2	128.0	492	59
D-1 Evaporation Units	42.1	66.6	148.0	119.0	376	97
1 Filter	6.0	0.3	124.0	37.2	167	10
1 Standby Filter	3.3		2.0		5	
Subtotal	51.4	66.9	274.0	156.2	548	107
E-2 Evaporation Units	84.2	95.5	152.0	150.0	482	194
1 Standby Filter	3.3		2.0		5	
Subtotal	87.5	95.5	154.0	150.0	487	194
F-1 Evaporation Units	53.2	93.5	152.0	148.0	447	136
1 Standby Filter	3.3		2.0		5	
Subtotal	56.5	93.5	154.0	148.0	452	136

* Power penalty is not included in weight summary.

** Sum of the heat rejection and process heat penalties.

Table 1.4-VI. Integrated Water Reclamation System Ratings

	WEIGHING FACTOR	SYSTEM					
		A	B	C	D	E	F
Minimum Cont. Level Reliability*	48	24.5	28.8	20.2	23.0	35.0	23.0
Design Cont. Level Reliability	10	1.3	1.6	2.2	3.3	2.7	4.8
Maintainability	8	4.4	5.0	5.8	6.8	6.4	7.2
Weight (Including Spares)	16	13.8	12.8	8.8	8.8	13.0	15.0
Power	18	11.5	14.2	15.3	13.5	10.8	12.6
TOTAL	100	55.5	61.4	52.3	55.4	67.9	62.6

* Drinking water 100%; wash water 50%; one unit failed; remaining unit operating 24 hr/day.

1.5 PROGRAM CONTROL

Program control planning was documented at many levels of detail and execution throughout the program. The primary planning documents were the "Program Plan," issued 8 July 1963, and the "Reliability and Quality Assurance Program Plan," issued 22 August 1963.

The Program Plan formally documented the contractor's approaches to:

- a. The type of organization to be employed and the identity of major personnel and contractor functions.
- b. The various engineering tasks and problems involved in the development program.
- c. The tests and test planning to be undertaken.
- d. The procurement and control of material.
- e. The contractor's manufacturing and equipment installation tasks.
- f. The preparation of the reliability and quality assurance program plan.
- g. The control of task assignments, costs, and schedule.
- h. The documentation and reporting of program progress, technical studies, coordination directives and meetings, and contractually defined engineering documents.

The Reliability and Quality Assurance Plan formally documented the contractor's understanding of and approaches to:

- a. Scope of the program.
- b. Selection of suppliers.
- c. Responsibilities of project personnel for execution of reliability and quality assurance tasks.
- d. The execution of reliability control in contractor and vendor design including: types of studies, specifications, reliability models and definitions, parts selection, design review and approval, and documentation.
- e. The execution of reliability control in contractor and vendor manufacturing and tests, including surveillance and coordination, source acceptance testing, inspection (both receiving and in-process), and documentation.

1.6 SUMMARY OF SELECTED SUBSYSTEMS

1.6.1 THERMAL CONTROL. Three interrelated thermal control circuits were developed to satisfy the system integrated thermal control requirements. These circuits were:

- a. The waste heat circuit, which conveys thermal energy from the power system simulator to components having high-temperature bulk heating requirements.
- b. The air circuit, which maintains a cabin air thermal environment conducive to crew comfort while acting as an intermediate fluid in absorbing the net connected heat gain from components.
- c. The low-temperature coolant-fluid circuit, which absorbs heat from the air circuit as well as from directly cooled components and rejects it to the space radiator system simulator.

Figures 1.6-1, -2, and -3 are simplified schematics of these circuits. The design and development of the circuits is more fully described in Sections 3.1 and 4.1.

1.6.2 ATMOSPHERIC CONTROL. The atmospheric control system regulates the constituents of the cabin atmosphere (excluding water vapor) by performing four major functions: (1) removal of CO_2 and regeneration of O_2 ; (2) removal of trace contaminants; (3) storage and management of N_2 and O_2 ; and (4) circulation of the cabin atmosphere.

The oxygen regeneration subsystem reclaims all the oxygen in the CO_2 respired by the crew and returns it to the cabin. Byproduct carbon is stored. The regeneration subsystem consists of the following functionally integrated equipment:

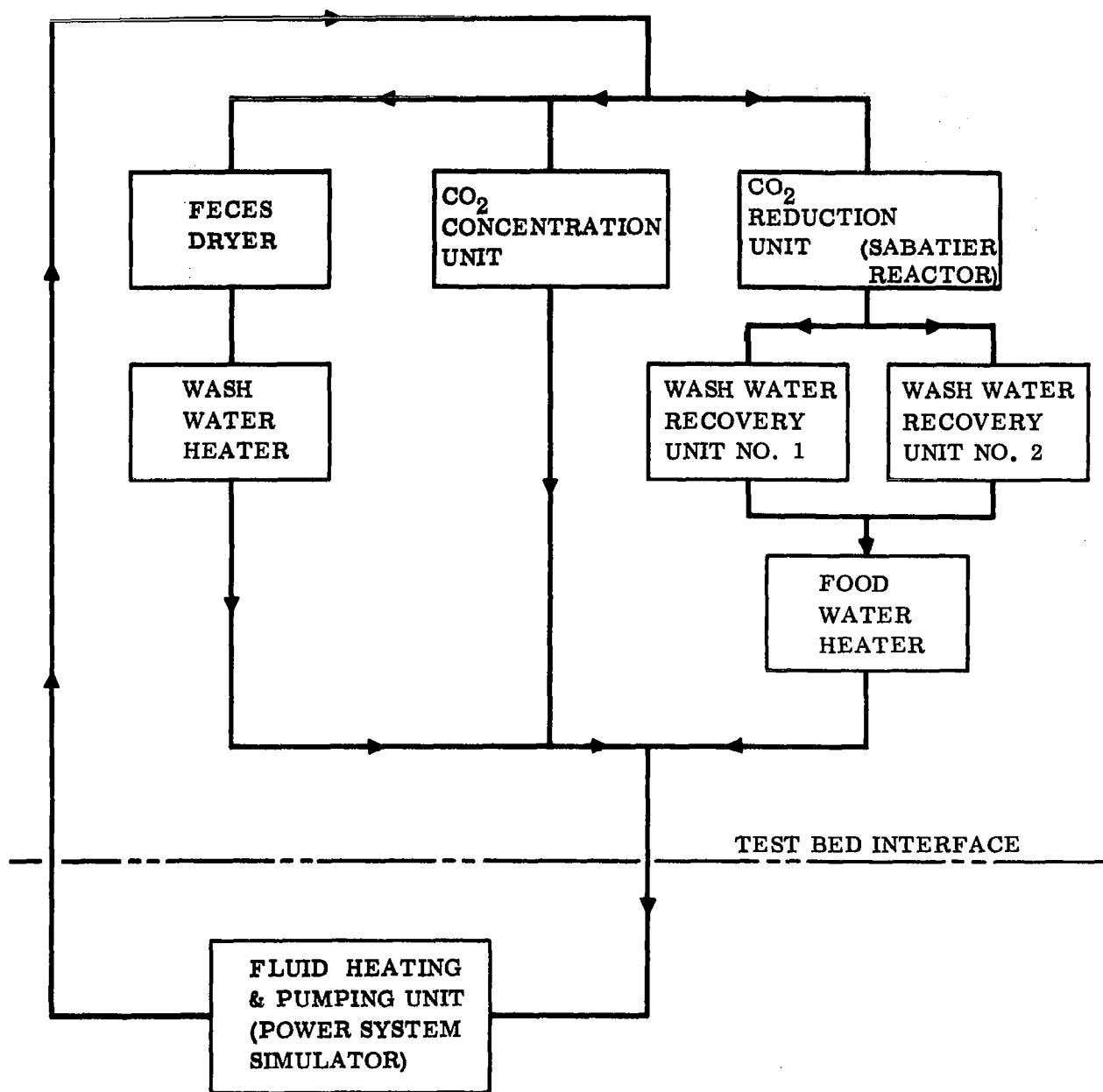


Figure 1.6-1. Process (Waste) Heat Circuit Flow Diagram

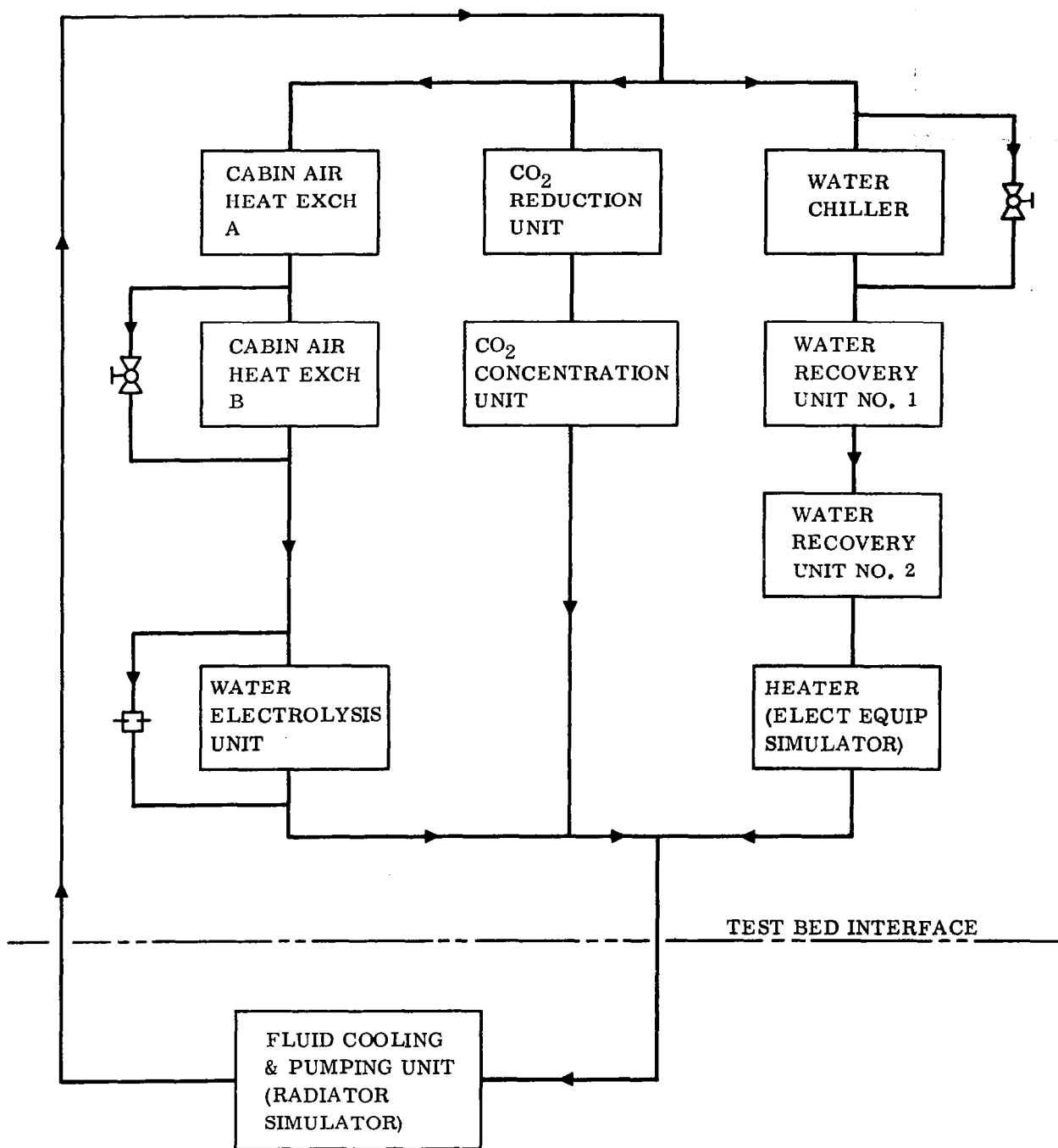


Figure 1.6-2. Liquid Coolant Circuit Flow Diagram

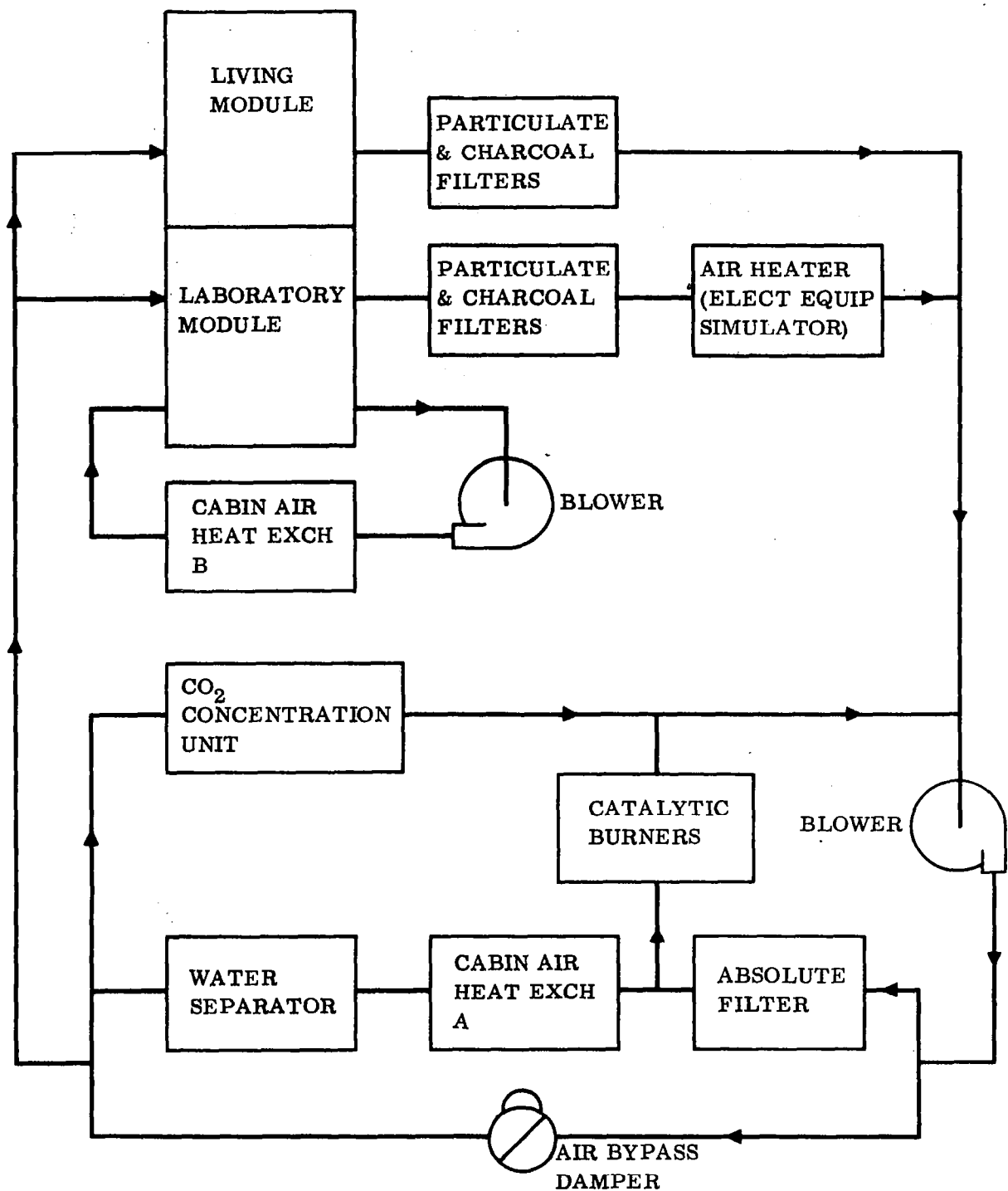


Figure 1.6-3. Air Circuit Flow Diagram

- a. A CO_2 concentration unit for CO_2 collection from the cabin air.
- b. A Bosch reduction unit, which converts the CO_2 and H_2 to H_2O and carbon.
- c. An electrolysis unit, which converts the H_2O to O_2 and H_2 , the H_2 being recycled to the reduction unit.

Trace contaminants are removed by continuously processing cabin air through: two catalytic burners, primarily for the oxidation of CO , H_2 , and CH_4 ; two charcoal filters for the removal of the higher-molecular-weight trace gases; and three fiber-glass filters for the removal of suspended matter in the cabin atmosphere.

Storage of N_2 and O_2 is required on board the spacecraft to make up for gas leakage and provide for cabin and air-lock repressurization. A subcritical cryogenic subsystem was recommended in the program studies for flight use. However, because the cost of such a system prohibited its use in the test bed, a subsystem of commercial gas cylinders, manifolds, and regulators was used.

The cabin air circulation subsystem includes blowers and duct outlets that provide adequate cabin air motion to prevent concentration gradients in the zero-g environment. Air circulation satisfies overall life-support equipment heat-transfer requirements as well as the comfort requirements of the crew.

1.6.3 WATER MANAGEMENT. The selected water management subsystem consists of two identical air evaporation units for normal-mode water recovery from urine, atmospheric condensate, and used wash water. (See Figure 1.6-4.) Stored water, in conjunction with a standby multifiltration unit for condensate recovery, is available for emergency use. Waste waters collected from the waste management urinal, personal hygiene sponge washing unit, cabin air dehumidifier circuit, and the Bosch reactor of the O_2 recovery function are transported, chemically treated, processed, tested, stored, and redistributed for use through hard-line circuits, manual control valves, and pressurized collection and storage tanks. The total nominal water inventory at any one time is approximately 300 pounds, including the emergency stored water.

The air evaporation unit employs a phase change as the primary mode of water purification. Vaporization takes place from wicks continuously saturated with waste liquids in a recirculating process air stream. The process air stream is heated across a heat exchanger employing a thermal-control system heating fluid. Process air temperatures are held below that which vaporizes other than the water content of the treated urine. A centrifugal water separator downstream of a condensing heat exchanger removes water from the air stream and pumps it to holding tanks for purity tests.

The standby multifiltration unit employs activated charcoal filters, an ion-exchange resin bed, and a bacteria filter for water recovery.

Waste water is chemically treated during the collection process to prevent growth of microorganisms and chemical decomposition.

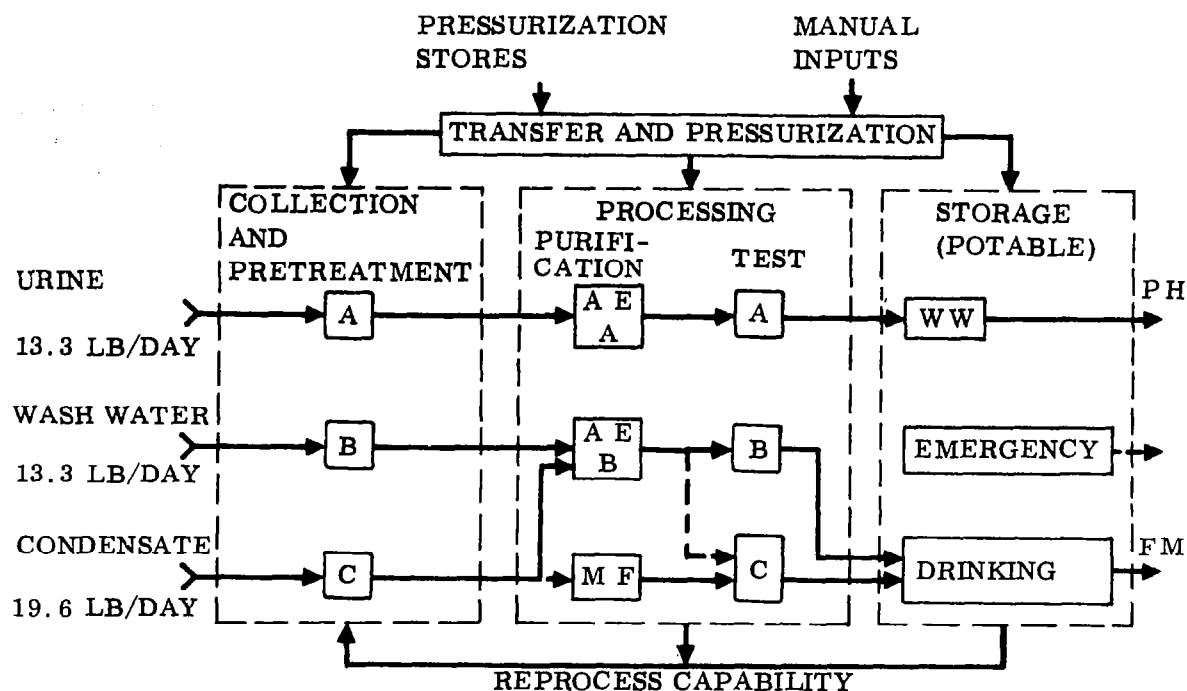


Figure 1.6-4. Water Management System

1.6.4 WASTE MANAGEMENT. The installed waste management subsystem is comprised of three basic modules, Figure 1.6-5. One module contains components for both the collection and drying of feces and the collection and transport of urine. The other two modules are identical waste storage assemblies. Both collectors employ a ducted air stream to direct the waste materials into the collectors under zero-g and to minimize cabin odors. The fecal collection assembly resembles a conventional toilet stool with provisions for collection of the feces in a semipermeable bag through which the velocity air stream passes. The feces are vacuum-heat dried in either of two drying chambers located within the basic module. Following drying, the feces still contained in the collection bag are placed in the storage assembly. Urine is collected directly from the crew member in a modified aircraft-type relief tube through which cabin air is drawn to facilitate transport of the urine to a liquid-gas separator. The separator, in turn, pumps the air-free urine to the water management subsystem.

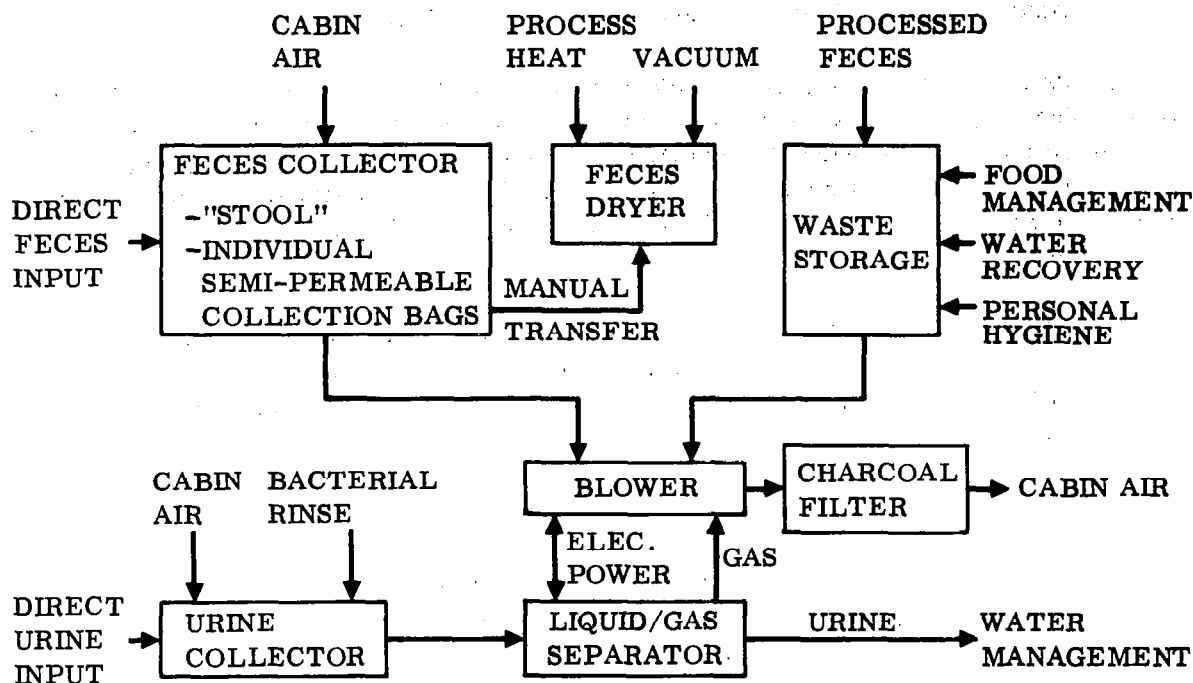


Figure 1.6-5. Waste Management System

1.6.5 PERSONAL HYGIENE. The installed personal hygiene subsystem includes the following equipment items.

<u>Task</u>	<u>Equipment Items</u>
Body Cleansing by Sponge Bathing and "Dry" (Chemical) Wipes	Zero-g sponge squeezer, water heater, liquid/gas separator, dry wipe cabinets and expendables, plus instruments and controls
Dental Cleansing by Toothbrush and Edible Toothpaste	Rack and brushes plus expendables
Grooming	Nail clip, electric shaver, and expendables

1.6.6 FOOD MANAGEMENT. Storage and preparation of food is provided by the following equipment.

- a. Supply cabinets for food storage.
- b. A food preparation console providing hot and cold water at specially designed metering dispensers.

- c. Thermally insulated trays designed to restrain foods in zero g.

Menus are designed to provide approximately 2,800 K cal/man-day in an attractive form. They consist of freeze-dried foods, dried concentrates of fruit, hydrated breads and confections, and dehydrated beverages. The processed foods and beverages are packaged in plastic containers configured to permit reconstitution and direct consumption under zero-g conditions. Foods not requiring reconstitution are bite-sized and wrapped in edible film.

1.6.7 INSTRUMENTATION AND CONTROL. The instrumentation and control system permits safe, controlled, manned and unmanned operation of the LSS test bed. The functions of the system are to: (1) sense and read out physical quantities (e.g., pressure, temperature, flow); (2) control certain quantities for stable operation; (3) warn the crew of impending failure; and (4) provide manual and automatic overrides to prohibit equipment self-destruction.

The design philosophy was to provide the most reliable, simple, rugged, and stable system possible within the overall system specifications. Crew capability and anticipated schedule were defined to establish the man-machine relationship. Normal and emergency operations were simulated to establish the overall system operational configuration requirements.

The final system is a composite of the equipment panels, onboard status panels, and the ground control console, linked by a failure warning and alarm system to provide information on system status.

About 240 detailed system requirements were established by system functional analysis, followed by a component failure and effect analysis. Instrument and control requirements were coordinated with subsystem vendors shortly after contract awards to guarantee overall system and interface compatibility.

Modifications in the instrumentation and control system were continually instituted to support equipment performance tests or modifications.

1.6.8 TEST BED

1.6.8.1 Configuration. An 18-foot-diameter steel pressure vessel forms the LSS test bed. The interior is arranged into two levels accommodating the LSS and crew.

The internal atmosphere can be controlled to range from near-vacuum to a positive pressurized state, with any percentage of air constituents. An air lock is provided so that passage to and from the test bed can be accomplished without disruption of the internal environment.

Aluminum supporting racks bolted to the internal walls, floor, and ceilings provide a secure mounting structure for all LSS equipment.

1.6.8.2 Acoustics. An acoustic treatment that assures effective room reverberation control over the broad frequency range of interest was developed. Approximately 75 percent of the internal test bed area is covered with mechanically applied, chemically inert fiberglass, securely encased in fiberglass cloth and lined with perforated aluminum panels. The floors are covered with pure nylon nontoxic carpeting.

1.6.8.3 Furnishings. Sleeping facilities for four men are provided on the upper level. Each bunk is enclosed by a curtain in an individual compartment, which also contains a reading lamp, storage drawer, and air conditioning outlet.

1.6.9 SYSTEM WEIGHT, VOLUME, AND POWER. Much of the LSS was modified and redesigned during the initial evaluation tests at Convair. In some cases, the modification resulted in a departure from the weight, volume, or power of the original design. Table 1.6-I reflects these changes, describing the system that was successfully demonstration-tested in July 1965 and delivered to NASA/LRC. Expendable stores and spares to be provided by resupply are not tabulated, nor is the initial water inventory required by the emergency provisions of the specifications.

1.7 SYSTEM TESTS

All systems were successfully integrated and tested in a 10-psia cabin on 13 July 1965 to demonstrate system operational characteristics for NASA/LRC observers. The electrolysis unit, CO₂ concentration unit, and reduction unit were connected to each other and operated as an integrated oxygen regeneration system, with the reduction unit in the Bosch mode of operation. The catalytic burners operated throughout the test, processing some bleed gas from the reduction unit, as well as cabin air. The concentration and reduction units were operated again on 15 July to demonstrate vacuum desorption and the Sabatier backup mode of operation.

1.7.1 TEST PROCEDURE. Subsystems were brought to stable operation at 1 atmosphere prior to testing at reduced pressure, because the catalytic burners and the CO₂ reduction unit require time for preheating, which is more easily monitored at 1 atmosphere. Except for the Sabatier reactor, subsystems were shut down before the test bed was pumped down. The initial CO₂ concentration and oxygen partial pressure at the 10-psia condition were established by admitting gas to the test bed from storage bottles; the test bed was then reoccupied by test personnel. The CO₂ produced by the test personnel was continuously processed and removed from the cabin atmosphere by the oxygen regeneration system.

Collection tanks of the water management system were partially filled with urine and used wash water prior to the test, since the test duration was considerably less than the several days required to establish a stable water inventory from biological

Table 1.6-I. System Weight, Volume, and Power

ITEM	WEIGHT (lb)	VOLUME (ft ³)	AVERAGE POWER (watts)
<u>Atmospheric Composition Control</u>			
CO ₂ Concentration Unit	486.4	23.9	896
CO ₂ Reduction System	321.0	26.0	1000
Water Electrolysis Unit	187.0	7.0	900
Catalytic Burner System	<u>198.0</u>	<u>16.0</u>	<u>166</u>
Subtotal	1192.4	72.9	2962
<u>Water Management</u>			
Evaporation Water Recovery System	249.9	23.6	93
Filtration Water Recovery Unit	9.3	0.4	5
Water Stores and Handling Equipment	<u>388.0</u>	<u>27.5</u>	<u>-</u>
Subtotal	647.2	51.5	98
<u>Food, Waste, and Personal Hygiene</u>			
Food Management System	698.5	60.0	26
Waste Management System	160.0	35.0	145
Personal Hygiene	<u>68.0</u>	<u>9.0</u>	<u>78</u>
Subtotal	926.5	104.0	249
<u>Thermal Control</u>			
Process Heat Circuit	70.0	-	33
Atmospheric Thermal Control Circuit	439.9	8.7	1530
Coolant Fluid Circuit	<u>113.0</u>	<u>-</u>	<u>290</u>
Subtotal	622.9	8.7	1853
System Total	3389.0	237.1	5172

processes. Pretreatment and transport operations were tested to demonstrate the functional adequacy of the expulsion and metering equipment, as well as the recovery of potable water from waste liquids.

The operation and temperature recovery of the food management water dispensers were demonstrated by withdrawing several samples of hot and cold water. The temperature of the hot water delivered by the dispenser had proven satisfactory for the reconstitution of food in previous tests at Convair.

One feces dryer of the waste management system was tested with a preparation of dry dog food and water. The container was removed from the dryer at intervals during the 10-psia condition and weighed. The drying process was continued after the other systems had been secured from the test and the test bed had been restored to atmospheric pressure, since the pressure and temperature within the dryer is independent of the condition of the test bed.

The thermal control air circuit was monitored for air and fluid flow rate, temperature, and relative humidity. Tests were run with two fluid flow rates and two dilutions of glycol solution, and with and without the cabin air-water separator.

The cabin atmosphere was sampled, analyzed, and recorded throughout the tests, and gas samples from units of the oxygen regeneration systems were obtained to assist in the operation and evaluation of the system. These tests were monitored by a physician to assure the safety of the test personnel.

1.7.2 TEST RESULTS. There were no instabilities or operational difficulties encountered in the tests, and all units were brought to full process rate or met specification requirements. The cumulative test time at 10 psia was six hours -- three and three-quarters hours on 13 July and two and one-quarter hours on 15 July.

The oxygen regeneration systems maintained a stable CO₂ concentration with a five-man crew in the test bed; the concentration increased slightly when two men were added. It was necessary, however, to use all the H₂ output of the electrolysis unit to obtain a four-man-level water catch from the reduction unit. Post-test inspection revealed a slight hydrogen leak in the mixture control package, which accounted for the high feed-gas requirement during the test. The regenerative heat exchanger performed as intended, recovering about 75 percent of the heat in the Bosch reactor discharge gases, while permitting carbon to pass on to the collection canister. The vacuum desorption and Sabatier backup mode of operation proved equally satisfactory, maintaining constant CO₂ concentration for a four-man crew. Cell voltages of the electrolysis unit did not increase significantly during the test, and the module temperature controls automatically maintained a temperature of 89° F on all modules. Catalytic burner S/N 001 was controlled at 710 - 780° F and S/N 002 was controlled at 700 - 740° F.

The temperature recovery of the hot water tank of the food management system was satisfactory. The temperature prior to water withdrawal was 162°F; following withdrawal, it dropped to about 150°F. The temperature was back to 162°F within an hour.

Operation of the water management system was without incident. Water collection, pretreatment, and transport were accomplished without difficulty, the pretreatment injection rate being about 6 cc/stroke. Separator rpm were 1825 and 2100 for units No. 1 and No. 2 respectively, and the corresponding process rates were 1.95 and 1.2 lb/hr.

The basket of the waste management feces dryer was easily removed and reinserted, and the vacuum valves functioned properly. After 16-1/2 hours of drying, the water content of a 573-gram specimen was reduced from 447 to 72 grams.

The thermal control permitted the laboratory module temperature to stabilize at 80°F near the end of the first day's test. The system was revised prior to the second test by increasing the coolant flow to the system B heat exchanger from 690 to 910 lb/hour and increasing the water content of the glycol solution. The temperature of the laboratory module stabilized at 65°F during the second test. Relative humidity was 49 and 59 percent respectively during the two tests. The range prescribed in the system performance specification is 40 - 60 percent.

Infrared scans of the atmosphere were made at least once each hour, and no significant contaminant levels were detected. Personnel were checked for symptoms, and none were found.

1.8 CONCLUSIONS AND RECOMMENDATIONS

The program objectives were effectively achieved, in that a four-man, integrated, regenerable life-support system has been developed and operationally demonstrated. The program has provided much needed insight to the practical problems of hardware development, and the conceptual aspects of the various subsystems have been evaluated and in most cases verified as feasible. Experience gained during this program will provide guidance for continued progress in the development of life-support systems for missions of extended duration.

The interdisciplinary skills and hardware testing utilized in the present program must be significantly expanded prior to the initiation of long-duration manned tests. Increased system efficiency could be obtained by utilizing processes that could recover and make use of the carbon produced during CO₂ reduction and now stored and of the excess hydrogen generated by the electrolysis unit and now discharged overboard. Conceptually, there are processes that appear promising for this use.

The following observations are based upon a review of system tests conducted under this program.

1.8.1 LEAKAGE. Nearly all the developed equipment required extreme care in fabrication and assembly to avoid unacceptable leakage of process fluids. Very little internal or external leakage could be tolerated from the reduction unit and catalytic burner, because of the possibility of introducing toxic gases into the test bed atmosphere.

The concentration unit was critical with respect to leakage from the standpoint of introducing air into the desorbing CO₂, thus reducing purity to an unacceptable level. This unit was also critical with respect to leaking moist air into the adsorbing zeolite system.

The waste management system was required to have low gas leakage to minimize the amount of cabin air that might be vented overboard and thus require added makeup from atmospheric stores. The cabin air-water separator seemed to leak air into the water cavity in a random fashion. This air must eventually be eliminated from the water management system; it could possibly become a problem if natural elimination of the air through the process air circuit of the air evaporation unit is found to be either inadequate to eliminate system problems or deleterious to subsystem performance.

The problem of minimizing gas leakage is greatly increased over that presented in standard engineering applications because of the very low process flow rates required of the equipment. Although it is recognized that essentially leak-free systems may be achieved, the importance of adequate consideration of this requirement and resultant system design aimed at achieving minimum leakage must be strongly emphasized in the initiation of future equipment design.

All liquid lines were subject to leakage at valves and line connections. For the fluids and temperatures used in this system, leakage is probable unless extreme care is taken with line connections and unless valves are selected with due regard to material characteristics when exposed to the liquids.

The electrolysis unit presented leakage difficulties in both the gas and liquid circuits. It is expected that a continuing leakage problem will be experienced with this unit because of the large number of connections required and the inherent characteristics in unit design.

1.8.2 WATER TREATMENT. Although testing was not sufficiently extensive to evaluate the proposed water treatment concepts fully, the experience gained does indicate that these concepts should be re-examined.

It is possible that the requirement for essentially bacteria-free water from the processing units may be made less stringent by considering thermal post-treatment for potable water and chemical post-treatment for the wash water supply. This treatment may eliminate the need for holding tanks and the accompanying requirement for making bacterial checks prior to introducing processed water into the potable system. The methods and equipment for the present chemical pretreatment of waste waters is questionable in terms of inherent accuracy, particularly when used in an engineering development program rather than as part of steady-state operational system. The problem arises from the fact that the liquid circuits must be free of gases to permit accurate metering of chemicals with the injector system.

1.8.3 INSTRUMENTATION AND CONTROLS. Instrumentation requirements must be carefully evaluated and equipment penetration points minimized to avoid the leakage problems.

System control requirements may be restrictive because of inherent subsystem design characteristics. An example of this is provided by the requirement for a relatively complex pressure-control system and operating procedure for the water electrolysis unit. This requirement is associated with the gas-liquid interfaces at the ion-exchange membranes and the porous separator plates. Pressure differential across the membrane is critical (because of the limited mechanical strength of the membrane), and the porous separator plate will allow liquid to back-flow through the separator unless proper differential pressure is maintained across the separator. The requirement for accurate pressure control is a result of integration of the electrolysis unit into the overall system and is a consequence of using a porous plate liquid-gas separator.

1.8.4 GAS ANALYSIS. On-line direct reading and recording instrumentation for much of the process gas analysis is recommended, since the requirement for trace-contaminant analysis frequently coincides with that for process gas analysis.

Problems encountered in evaluating standard samples indicated interaction of compounds either during freeze-out or thawing and volatilization of samples for analysis. Techniques should be developed to identify primary contaminants more effectively.

Improved techniques with high sensitivity will be required to identify and monitor trace contaminants within the test bed. Multiple techniques are desirable to substantiate the identification of contaminants and to ensure reliable information regarding safe contaminant level during manned tests.

1.8.5 SUBSYSTEM AND COMPONENT FUNCTIONS

1.8.5.1 Electrolysis Unit. The fundamental problem experienced during the test program was degradation of the cell membrane assemblies. Degradation was believed

to be directly attributable to operation with a design cell temperature of approximately 150°F. A temperature control was installed to limit cell temperature to about 90°F, and no further degradation was observed. This is not significant, however, as very little operational time was accumulated after incorporation of the lower cell temperature. If additional testing still indicates unacceptable cell degradation, a new or radically modified cell configuration will be required.

1.8.5.2 Liquid-Gas Separators. Both static and dynamic liquid-gas separators were employed. The static separators utilized a porous plate as a liquid-gas interface and depended on capillary forces in the pores to prevent gases from passing through the plates. The dynamic system utilized centrifugal forces from a rotating assembly, driven by either a direct-connected air turbine or an electric motor.

As originally designed, all the separators failed to function properly, although component modification permitted satisfactory subsystem operation. A development program is needed to produce operational separators.

1.8.5.3 Zero-g Process Verification. Although all equipment was conceptually designed to be compatible with a zero-g environment, it was not possible to verify these concepts. As the system matures, it is recommended that a systematic parallel program be developed to test and verify selected processes for gravitational dependency. This would eventually evolve into a system flight test program with candidate subsystems having been screened by the initial phases of such a program.

1.8.5.4 Energy Conversion. It has been demonstrated that thermal energy can be effectively utilized in critical life-support system processes through the application of waste heat supplied through a liquid transport circuit. This is significant because electrical energy requirements may be reduced or may be allocated to more restrictive applications.

1.8.5.5 Ground Support Equipment. The ground support equipment providing process heat fluid to the life-support equipment was initially deficient in operation. Problems of inadequate fluid temperature control and of fluid contaminant generation within the unit itself due to materials incompatibility were encountered. Modification and installation of filters prevented contamination of the life-support equipment being supplied. Filtering systems should always be provided to prevent contaminant transport and to allow replacement of filters without system shutdown.

1.8.6 GROWTH OF MICRO-ORGANISMS. There has been no opportunity to investigate the potential problem of micro-organism growths in filters and other elements of the LSS and test bed. The research program at NASA/LRC should include a comprehensive study of the microbiological controls appropriate to long duration manned testing.

SECTION 2

OVERALL SYSTEM SPECIFICATION

This section presents the broad LSS program guidelines and criteria. The specifics were established during the first month of the program and revised as the program progressed, to assure proper direction and emphasis. The detail subsystem specification and component procurement specifications are presented in Sections 4 and 5 respectively.

2.1 LIFE SUPPORT SYSTEM

The LSS shall maintain environmental control within the manned compartments of a spacecraft and provide materials and facilities for the crew's metabolic needs and waste elimination. Crew safety, fitness, and comfort are guidelines for achieving these functions. The system functions shall comprise subsystem functions in categories as follows.

- a. Atmospheric Control
- b. Thermal Control
- c. Food, Water, and Waste Management
- d. Controls and Instrumentation
- e. Life Support System Test Bed

Although controls and instrumentation are inherently parts of the other subsystems, they are designated collectively as a subsystem to be consistent with requirements for integration of the other subsystems. The test bed is designated as a subsystem because its functions are not completely within any of the other subsystems.

2.1.1 ATMOSPHERIC CONTROL. Atmospheric control includes the pressurization, air circulation, and the control of air composition within the cabin.

Cabin total pressure is controlled by means of regulating devices. Gases are stored and supplied to make up losses that may result from leakage and/or decompression.

Air circulation is the transport of air through processing components by means of blowers, ducts, and fittings; it is controlled by valves, dampers, and diverters. The circulation pattern within the cabin is achieved by nonducted fans and by inlet and outlet grilles, vanes, diffusers, nozzles, and other fittings at points where air enters the cabin from processing components and leaves the cabin to enter processing components.

Air composition control includes the following functions.

- a. Regulating O_2 partial pressure by a continuous or intermittent feed that replaces the losses.
- b. Regulating CO_2 partial pressure by processing to separate CO_2 from cabin air.
- c. Regulating H_2O partial pressure by processing to separate H_2O from cabin air.
- d. Processing to remove odors.
- e. Removal of contaminant particles.
- f. Processing to maintain concentrations of gaseous contaminants below the maximum allowable.
- g. Processing to recover O_2 from CO_2 .

2.1.2 THERMAL CONTROL. Thermal control of temperatures and heat flux in all components except the power source is required.

Air is cooled, as required, to maintain cabin air temperature within a specified range. Cooling rejects heat absorbed by the air from the crew and equipment and achieves humidity control.

Means of cooling all heat-producing equipment is provided so that equipment temperatures can be maintained within specified limits.

Heat rejection is defined as the total controlled heat flux from the cabin to its surroundings. At equilibrium temperatures, the total heat rejected equals the total heat input to the cabin from all sources. A spacecraft using minimum expendables can reject heat only by thermal radiation to its surroundings. This LSS, however, uses a refrigeration apparatus with heat exchangers to simulate the performance of a space radiator.

Heat transport is the controlled transport of thermal energy from its source to the place of heat rejection. A heat transport fluid loses thermal energy by convective heat transfer to the space radiator and is circulated back to the heat source.

2.1.3 FOOD, WATER, AND WASTE MANAGEMENT. Food management functions include storage and reconstitution of food, and heating and chilling of potable water.

Water management functions include water storage, testing, and reclamation.

Functions of waste management include waste collection, transfer, processing, and storage or disposal. Wastes to be collected include feces; urine; debris from shaving, hair cutting, and nail clipping; food wastes; packaging material; vomitus;

disposable sanitary supplies; spent filters; and carbon and possible other residue from LSS components or from scientific experiments. Processing of wastes may include disinfecting, decomposing, incinerating, desiccating, or freezing as means of inhibiting bacterial growth.

2.1.4 CONTROLS AND INSTRUMENTATION. Functions of the controls and instrumentation subsystem include sensing and readout of such physical quantities as temperature, pressure, flow, and electrical power; the means of controlling certain of these quantities in other components and subsystems of the LSS; and alarms to warn of critical malfunctions.

2.1.5 LIFE SUPPORT SYSTEM TEST BED. The test bed provides a means of testing the LSS. The interior dimensions and arrangement conform with the spacecraft model. Additional test instrumentation is used externally to supplement the LSS controls and instrumentation subsystem.

2.2 MODEL CRITERIA

The engineering constraints for analysis and design of the LSS were based upon a hypothetical but realistic series of models. The design criteria and guidelines established for the mission model, spacecraft model, and crew model are presented in the following paragraphs.

2.2.1 MISSION MODEL. Table 2.2-I presents the specific mission model criteria that affected the analysis, selection, and design of candidate life support subsystems and the total integrated LSS. The orbital elements and the attitude program are primarily for calculating thermal radiation exchange of the spacecraft cabin with the environment.

It has been established for this mission model that mission emergency procedures involving crew escape and rescue are not significant in establishing LSS design criteria. Emergency provisions, however, are required for LSS malfunctions or failures.

2.2.2 SPACECRAFT MODEL. The spacecraft model is a cylinder 220 inches in diameter by 215 inches long. Size and locations of air lock, emergency hatches, access doors, viewing ports, interface panels, and stairway are in accordance with Drawing 64-02001.

The atmospheric quantities required for the spacecraft are based upon the data presented in Table 2.2-II.

The thermal control system for the spacecraft and the LSS is based on the following characteristics:

Table 2.2-I. Mission Model

Operational Period	1967
Mission Duration	1 year
Mission Objectives	Scientific experiments
Resupply Capability	
Frequency	90 days
Weight	Minimum
Volume	Minimum
Orbital Elements	
Eccentricity	Zero
Altitude	250 n.mi.
Orbit inclination (solar vector)	30 degrees
Attitude Program	
Vehicle axis (cylinder)	Normal to solar vector
Vehicle rotation	Zero
Gravity	1 - zero g

a. Radiators for Heat Rejection

Configuration	External cylindrical surface of vehicle
Orientation	Same as vehicle
Radiative Interchanges with Other Vehicle Surfaces	None
Structure	Fin-and-tube, with outer skin of vehicle serving dual purpose of meteoroid armor and fin material

b. Heat Rejection from On-Board Equipment. (See Table 2.2-III.)

Table 2.2-II. Spacecraft Atmospheric Quantities

	VOLUME (ft ³)
Living Module	2240
Laboratory	1910
Total Cabin	4150
Air Lock	90
Total Spacecraft	4240
	LEAKAGE RATES (lb/mo)
Cabin	32.7
Air Lock	0.8
Total	33.5
Air Lock Operation:	5 cycles/90 days
Total Spacecraft Repressurization:	Once/90 days

c. Cabin Wall Thermal Properties

Mean radiant temperature of cabin wall inside surface	Within 5° F of cabin air temperature
Local temperature of cabin wall inside surface at any point	Above cabin air dew point
External surface solar absorptivity	0.16
External surface infrared emissivity	0.85
Inside surface convective film coefficient	1.0 Btu/hr-ft ² - °F

Table 2.2-III. Heat Rejection from On-Board Equipment

	POWER LEVEL (watts)		TOTAL
	CONTINUOUS	INTERMITTENT*	
Tracking		84	84
Intercommunications	10		10
Communications and Data Handling	266	798	1064
Attitude Control	160		160
Inertia Wheels	300		300
TV	231		231
Rendezvous**		300**	300
Displays	10		10
Lighting	150		150
Experiments	735		735
Totals	1862	882*	3044

*Six-minute duration, 36 times per day.

**Two-hour duration, once per 90 days.

Cabin wall thermal conductance $0.02 \text{ Btu/hr-ft}^2\text{-}^\circ\text{R}$

The model indicates that the power system radiator is oriented with the spacecraft and that there are no radiative interactions between it and the LSS radiator. The radiator structure is significant in weight tradeoff studies. Only tubes and fluid are chargeable to the LSS, since the fin material is part of the spacecraft structure.

The following weight and power criteria were established for the spacecraft model.

Power Penalty	290 lb/kw
Maximum Power Available	5 kw (2 - 2.5 kw maximum for LSS)
Heat Rejection Penalty	Sensible 0.01 lb/Btu/hr
Waste Heat (Power Supply)	Basically unlimited

Power Quality

Three-phase, 115 - 208 vac, 400 cps
 $\pm 1\%$

28 vdc $\pm 1\%$

2.2.3 CREW MODEL. The normal crew is four, two each in the living module and the laboratory. LSS capability for six men (four crew plus two from ferry vehicle) is required for three hours once every 90 days. A crew distribution of all four in one module is considered an emergency condition, except for brief periods as a convenience to the crew. A crew distribution of three men in either module and one in the other is considered the occupancy range within which the LSS shall maintain an environment continuously within nominal performance specifications.

Table 2.2-IV represents the average metabolic criteria per day for a 37-year-old, 55th-percentile male.

Table 2.2-IV. Metabolic Criteria

	QUANTITY PER-MAN-DAY		
	MAXIMUM	MINIMUM	DESIGN POINT
O ₂ Uptake, lb	1.87*		1.87
CO ₂ Output, lb	2.32*		2.32
Food, Ashless, Dry Basis, lb	1.38		1.38
Water of Oxidation, lb		0.72	0.72
Water Allowance, lb	7.72	6.17	7.72
Urine Water, lb	4.13	2.20	3.30
Fecal Water, lb	0.33	0.22	0.25
Urine and Fecal Solids, lb			0.22
Evaporative Water Loss (Respiration and Perspiration), lb	5.90	2.54	5.90
Latent Heat, Btu	6191	2659	6191
Sensible Heat, Btu	8453**	4921	8453

* These are design values which do not represent concurrent O₂ consumption and CO₂ output. Therefore, they do not represent a specific respiratory quotient.

** Does not occur concurrently with maximum latent heat. Sum of sensible and latent is constant at 11,112 Btu/man-day.

The daily activity schedule for a crew member, with corresponding metabolic O_2 , CO_2 , and H_2O rates, is shown in Table 2.2-V.

The metabolic excursions due to an emergency have been established for a maximum period of one hour. Table 2.2-VI presents the emergency metabolic criteria.

Table 2.2-V. Daily Activity Metabolic Criteria

ACTIVITY	TIME (hr)	RATE (% BMR)	O_2 UPTAKE (lb)	POUNDS PER MAN-HOUR	
				CO_2 OUTPUT (lb)	H_2O EVAPORATION (lb)
Normal Duties	8	135	0.070	0.087	0.221
Off Duty	6	100	0.052	0.0645	0.164
Exercise	2	600	0.312	0.3867	0.984
Rest	8	90	0.047	0.058	0.1475
Average		150	0.078	0.0967	0.246

Table 2.2-VI. Emergency Metabolic Criteria (One Hour)

ACTIVITY	O_2 UPTAKE (lb)	CO_2 OUTPUT (lb)	H_2O EVAPORATION (lb)	METABOLIC HEAT (Btu/hr)
Two men @ 150% BMR	0.156	0.193	0.492	928
One man @ 500% BMR	0.260	0.322	0.82	1543
One man @ 1000% BMR	0.520	0.644	1.64	3085
Average 450% BMR	0.935	1.16	2.95	5556

2.3 PERFORMANCE REQUIREMENTS

The LSS shall have an operating lifetime of not less than one year. This requirement does not preclude supply and maintenance procedures as follows.

- a. Expendable materials and supplies will be continuously available from stores on board at launch or brought on board by resupply operations.
- b. Scheduled maintenance will be performed by the crew.
- c. The crew will be assumed to have skills and tools necessary to perform scheduled maintenance and make repairs not within scheduled maintenance procedures. Provision of tools is not within this contract.
- d. The expendable materials available will include filter elements, gaskets, seals, and other small parts that may have operating lifetimes of less than one year.

The capacity for storing food, water, oxygen, nitrogen, sanitation supplies, filter elements, and spare parts shall be for a nominal 90-day operating interval between resupply events, plus 10 days in reserve.

The design objectives for maximum combined intensity of acoustic noise from all LSS sources shall be as shown in Tables 2.3-I and 2.3-II.

Table 2.3-I. Laboratory Area Criteria

OCTAVE BAND (cps)	SOUND PRESSURE LEVEL (db re 0.0002 microbar)
20-75	72
75-150	66
150-300	61
300-600	56
600-1200	53
1200-2400	50
2400-4800	47
4800-9600	43

Table 2.3-II. Living Area Criteria

OCTAVE BAND (cps)	SOUND PRESSURE LEVEL (db re 0.0002 microbar)
20-75	69
75-150	65
150-300	60
300-600	54
600-1200	50
1200-2400	46
2400-4800	42
4800-9600	38

2.3.1 THERMAL CONTROL. The thermal control subsystem shall provide a "shirt-sleeve" environment within the cabin. This environment is considered to mean comfort for an average crew performing average duties and attired in light fabric undergarments and light fabric flight suits. This requirement does not preclude the use of optional clothing by the crew.

The thermal control subsystem shall be capable of maintaining the dry bulb temperature of the cabin air between the limits of 68°F and 80°F at any point more than 6 inches from a cabin floor, wall, or equipment surface and more than 2 feet from an air discharge or intake fitting. The emergency limit for one hour or less shall be 85°F. This requirement shall not apply to equipment spaces, storage compartments, or other spaces not designed to be occupied by the crew. For evaluation of the shirt-sleeve environment, it shall be considered that the mean radiant temperature of the inside surface of the cabin wall is within 5°F of the cabin air temperature.

The thermal control subsystem shall provide protection for all equipment within the cabin. This includes means of cooling heat-generating equipment items such as electrical, electronic, and chemical process components. All equipment of the LSS, together with all items listed in paragraph 2.2.2 constitute the equipment cooling load. For the items in paragraph 2.2.2, the following cooling means shall be employed.

	<u>Heating Load (Watts)</u>	
	<u>Continuous</u>	<u>Intermittent</u>
Convection to cabin air	718	310*
Cold plate to liquid heat transport fluid	1144	572**

* Six-minute duration, 36 times per day

** Two-hour duration, once per 90 days

Heat loads from paragraph 2.2.2 items that are not a part of this contract shall be simulated by electric resistance heaters. The thermal control subsystem shall also supply heat, if required, to limit the lower temperature of equipment.

Forced convection of a fluid shall be employed to transport thermal energy from within the cabin to a heat rejection component outside the cabin. Temperature of the fluid shall not exceed 150°F. The thermal control subsystem shall be designed to reject heat by means of a space radiator having the geometry and environment indicated in the mission and spacecraft models. Such a radiator shall be simulated by a refrigeration apparatus and heat exchangers, which shall provide a constant flow and constant temperature to the LSS.

The heat load to be rejected shall include the following.

- a. Crew metabolic heat load (reference paragraph 2.2.3).
- b. Electrical and electronic heat load (reference paragraph 2.2.2).
- c. LSS heat load.
- d. Cabin wall heat flux.

2.3.2 ATMOSPHERIC CONTROL. The atmospheric control subsystem shall maintain the cabin atmosphere continuously within the specifications in Table 2.3-III.

Table 2.3-III. Cabin Atmosphere Specifications

	ONE-HOUR EMERGENCY LIMITS	MAXIMUM	MINIMUM	DESIGN POINT
Cabin Total Pressure, psia		15.0	10.0	10.0
Oxygen Partial Pressure, mm Hg	140 to 180	165	150	160
Nitrogen Partial Pres- sure				Diluent
Carbon Dioxide, mm Hg	15.2	4.2	--	3.8
Relative Humidity, percent	90	60	40	--
Odor Standards		Not objectionable to crew.		
Toxic Gaseous Contam- inants		1/10 industrial threshold limit.		
Particle Contaminants		Not hazardous to crew		

The ventilation criteria of the main cabin air circulation blower and auxiliary fans are as follows.

	<u>Maximum</u>	<u>Minimum</u>	<u>Design Point</u>
Ventilation rate for cabin, cfm/man	-	30	125
Ventilation air velocity over cabin occupants, ft/min	40	10	15

The atmospheric control subsystem shall have the capability for one complete repressurization of the cabin. It shall also have capability for a series of partial repressurizations, the sum of which shall be equal in quantities of gases to one complete repressurization. The time of gas flow to repressurize from zero to 10 psia cabin total pressure and to 100 mm Hg of oxygen partial pressure shall not exceed two hours.

The atmospheric control subsystem shall include components for regenerative processes to: (1) adsorb or absorb CO₂, with a process to separate the CO₂ and regenerate the adsorbent or absorbent; and (2) recover oxygen from CO₂.

2.3.3 WATER MANAGEMENT. The water management facilities shall provide for storage and zero-g dispensing in the living module for all potable and waste water. The total inventory of water stored on board, excluding any that may be stored for electrolysis to supply O₂, shall be 240 pounds.

Water allowances shall be as follows.

	<u>Pounds/Man-Day</u>	<u>Total (lb/day)</u>
Drinking and Food Preparation	7.49	29.96
In Food	.23	.92
Total Consumption	7.72	30.88
Personal Sanitation	3.30	13.2
Totals	11.02	44.08

Waste liquids shall be processed to recover potable water for consumption by the crew and for personal sanitation use. The processing apparatus shall have capacities as follows.

	<u>Pounds/Man-Day</u>	<u>Total (lb/day)</u>
Urine	3.30	13.2
Humidity Condensate	4.89	19.56
Wash Water	3.30	13.2

The urine output of the several astronauts shall be mixed before processing. Dehumidification water shall be recovered in separate processing apparatus. Separate (unmixed) storage shall be provided for liquids in the following categories.

- a. Urine
- b. Water recovered from urine.
- c. Waste wash water.
- d. Humidity condensate.
- e. Potable water recovered from humidity condensate and waste wash water.
- f. Reserve potable water in living module.
- g. Batch quantities from water recovery units for quality analysis.

2.3.4 WASTE MANAGEMENT. Facilities shall be provided in the living module for primary waste management and personal hygiene facilities. The waste management facilities shall perform as specified with the maximum waste inputs shown in paragraph 2.2.3.

Facilities provided shall include means of performing the following in a convenient, sanitary, and inoffensive manner.

- a. Collect wastes, including feces, urine, vomitus, food residues, packaging, used paper products, cleaning agents, nasal discharges, hair, nail clippings, and other body debris.
- b. Transfer wastes from collection devices to processing and/or storage devices.
- c. Process and/or store wastes such that bacteria, odors, and decomposition products are eliminated or contained.

2.3.5 PERSONAL HYGIENE. Techniques and equipment shall be provided for body cleansing, dental cleansing, and grooming. The techniques and equipment must be uncomplicated, psychologically acceptable and amenable to the zero-g environment.

2.3.6 FOOD MANAGEMENT. Food management facilities shall provide for the 90-day resupply interval plus 10 days in reserve. The facilities shall include means for the crewmen to handle and consume foods and beverages in a zero-gravity environment.

Food storage shall be in the living module. The packaging and storage methods shall be consistent with requirements for shelf life and shall be designed to facilitate the removal of a single meal for a single crewman.

The packaging methods and materials shall be weight-optimized and shall be chosen to facilitate sanitary disposal of the packaging. The packaging shall also be consistent with, and facilitate the preparation of, foods for consumption by hydrating and/or heating or chilling.

Food shall be packaged in four general groups:

- a. A complete, one-package main dish with a well-balanced, interesting combination of foods. This will be the standard basic unit. There will be many food combinations in main dish units for breakfasts, lunches, and dinners.
- b. Individual packets of variety food preparations for a crew member to assemble a menu that suits his individual preference. Beside dried foods, packets will include candies, nuts, olives, cheeses, and other snack-type supplements.
- c. A smaller number of special accessory foods to be served every Sunday or for special occasions, such as each crewmember's birthday.
- d. An emergency food supply in the laboratory module.

The food allowance shall be approximately as follows.

<u>Pounds per Man-Day</u>			
	<u>Hydrated</u>	<u>Dehydrated</u>	<u>Total</u>
Food, Including Moisture	0.37	1.35	1.72
Packaging			0.20
Total	0.37	1.35	1.92
Moisture in Food	0.13	0.10	0.23

2.3.7 CONTROLS AND INSTRUMENTATION. Controls and instrumentation shall be provided in two categories.

- a. LSS flight-type instrumentation and controls, including all those that are inside the test bed and that provide information and control capability directly to the crew. This equipment shall be considered part of the LSS.
- b. LSS ground laboratory-type controls and instrumentation that enable a ground test crew to determine safety and to measure performance of various components and subsystems. This equipment will have sensors and actuators within the test bed, but the displays and some operating controls will be external. Items in this category shall be contractor facilities and shall not be delivered with the LSS under this contract.

The LSS shall have an automatic control system, based upon a functional analysis of system requirements. Manual overrides and variations in the degree of automaticity shall be provided in accordance with human factors criteria of paragraph 2.4. Controls shall be designed for optimum use of crew capabilities. Items critical to crew safety shall have audible and/or visual alarms, coded to identify the malfunction. All controls essential to crew safety shall be operable by a single crewman wearing an inflated pressure suit in a zero-g environment. Controls shall have design characteristics that prevent man-induced failures of the LSS and inadvertent actuation of emergency modes. Manual overrides shall be located directly on equipment to the maximum extent feasible.

Controls instruments and displays of the flight-type category shall include the following.

	<u>Living Module</u>	<u>Laboratory Module</u>
Air Temperature	X	X
Total Pressure	X	
O ₂ Partial Pressure	X	X
CO ₂ Content	X	X
Humidity	X	X
Air Flow	X	
Gas Analyzer	X	
Stored Gas Quantity	X	
Stored Water Quantity and Quality	X	

2.4 HUMAN FACTORS CRITERIA

2.4.1 CREW PERFORMANCE. The crew members will be considered to have the following general attributes influencing LSS design.

- a. Experience. All crewmen will have engineering test pilot experience, with emphasis on flying skills. They will have relatively little experience in equipment maintenance, except for that acquired during the astronaut training program.
- b. Adaptation to Space Living Conditions. Through extensive training in mission simulators, crewmen will be conditioned to living conditions that are more restrictive than normal. They will be conditioned to accept the following without loss of efficiency: (1) no smoking, (2) smaller quantities of water for hygiene purposes and (3) unorthodox equipment and/or procedures for food preparation and consumption, personal hygiene, and other life-support functions.

2.4.2 CREW INTEGRATION. The LSS shall be designed for optimum utilization of flight crew capabilities. Assignment of operational or maintenance functions shall be based on systematic analysis of the capabilities, limitations, and requirements of the crew members.

2.4.3 CREW COMFORT. For efficiency and habitability, the LSS shall be grouped and configured into separate functional areas as follows.

- a. LSS control and maintenance.
- b. Toilet, waste disposal, and personal sanitation.
- c. Food storage and preparation.
- d. Sleep and rest.
- e. Recreation.
- f. Emergency egress.
- g. Mission operations work.

Storage capacity shall be located within the functional areas as follows.

- a. LSS operation and maintenance provisions (checklists, technical manuals, tools, test kits, spare modules, etc.), in the control and maintenance area.
- b. Personal sanitation provisions (cleansers, cleaning tissues, waste disposal bags, water containers, shaving equipment, nail clippers, etc.), in the toilet area.
- c. Food service equipment (food packages, water reservoirs and dispensers, food heaters, etc.) in the food storage and preparation area.
- d. Crew personal equipment storage (clothing and other items reserved for the sole use of individual crew members) in the sleep and rest area.
- e. Recreation equipment and possibly clothes cleaning equipment in the recreation area.
- f. Pressure suits and associated equipment adjacent to the air lock. If six pressure suits are used, two will be stored within the air lock.

The following criteria will be used for food selection.

- a. Food and beverage supplies shall be optimized with respect to flight crew preferences of odor, taste, variety, appearance, consistency, and other characteristics affecting acceptability and palatability.
- b. The balance between protein, fat, and carbohydrates shall meet metabolic and palatability requirements.
- c. The diet shall contain adequate amounts of essential amino acids, minerals, and proteins.

2.4.4 CONTROLS. The location, spacing, functional groupings, and information feedback from the controls shall be within the visual field of a helmeted man and operable within his reach envelope. However, since weightlessness removes the restriction of close grouping (because whole body movement and translations can be made over large areas), an open-panel layout is possible.

Alarms and warnings, beside meeting standard human engineering requirements for loudness and visibility, shall meet the needs of a free-floating, space-suited crewman oriented in the cabin in any possible position. Critical control positions shall activate warnings in the affected areas and work stations. All critical controls shall require precontrol action (such as activating an interlock or removing a guard) before they are enabled.

There shall be an emergency fast air clearance and purification mode in case of large-volume fume generation, as from a flashfire or chemical spillage. Emergency equipment shall be in readily available locations.

2.5 TEST BED REQUIREMENTS

The test bed shall have a boilerplate hull providing a closed environment. It shall permit LSS operation and testing either with or without occupancy by a crew.

2.5.1 CONFIGURATION. The test bed shall conform within 5 percent in volumes and dimensions to the spacecraft model. (See paragraph 2.2.2.) It shall be erected such that the gravity vector acts opposite to the inertia force vector during boost of the spacecraft. (The spacecraft is inverted during launch.)

2.5.2 UTILITIES. The test bed shall have connectors for the following utilities.

- a. **Electric Power.** Input conforming to capabilities of the spacecraft model electrical power system. Connectors shall also be provided for shop use, laboratory lighting, and operating equipment other than the LSS.
- b. **Ventilation.** Ground Source.
- c. **Communications.** Two-way communication between occupants and personnel outside.
- d. **Vacuum.** Shop or laboratory vacuum facilities to simulate the space environment. Connectors shall permit vacuum to be applied to the air lock and/or the cabin and any process equipment designed to use the vacuum of space.

2.5.3 EXTERNAL INSTRUMENTATION. The test bed shall have controls and instrumentation as stated in paragraph 2.3.7. It shall also provide for use of biomedical instrumentation, which is not part of the system under this contract.

2.5.4 HEAT REJECTION. The test bed shall include means of rejecting heat from the LSS to a refrigeration system simulating a space radiator. The heat rejection capacity of the simulator shall exceed the maximum heat loads indicated by at least 50 percent.

2.5.5 FURNISHINGS. The test bed shall have furnishings consistent with requirements of the mission, spacecraft, and crew models. Furnishings shall include:

- a. Privacy provisions and storage facilities in the toilet area.
- b. Privacy and acoustic control provisions, bunks, and storage facilities in the sleep and rest area.
- c. Lighting for all areas.

2.6 DEFINITION OF PROTOTYPE DESIGN

2.6.1 DESIGN CONSIDERATIONS. Installed equipment shall be grouped for functional efficiency and access for inspection, maintenance, repair or replacement. The degree of accessibility is to be determined by the anticipated maintenance schedule. Any sub-assembly designated for replacement rather than repair, because of safety hazard, zero-g handling difficulty, or physical complexity, shall be marked and assembled so as to prevent inadvertent disassembly.

The LSS shall be so designed to sustain normal handling and shipping forces and to operate in any force field from zero to 1 g. Design characteristics shall be compatible with the development of flight articles able to withstand typical launch environments. Equipment designated for emergency use during a decompression shall be designed for operation at zero pressure.

All components shall reflect the principles, fundamentals, and basic size of final flight hardware but shall not necessarily be the ultimate from the standpoints of weight, bulk, and detailed design. Whenever possible, existing hardware or proven design principles shall be used. All components shall be small enough to fit through air lock hatches.

Manual overrides and crew adjustment shall be provided for automatic control systems. Whenever possible, manual overrides in lieu of remote electrical overrides shall be an integral part of the equipment. Direct-reading instruments at the equipment location shall be used whenever practical. All electrical loads shall have automatic overload and thermal cutoff circuitry to prevent permanent damage or fire hazard due to insulation breakdown. Lights and/or annunciators, operated by power and/or thermal sensing devices, shall warn of equipment cutoff.

The LSS and test bed shall be designed for manned or unmanned testing. Power, communication, instrumentation, ventilation, vacuum, and control interfaces shall

be provided to permit external monitoring of the LSS. Isolated, protected, standard industrial-type electrical power outlet boxes shall be provided at convenient locations inside the test bed.

2.6.2 ANALYTICAL CONSIDERATIONS. Selection of subsystems and components shall be based upon the following criteria, listed in order of priority.

- a. Reliability and maintainability.
- b. Weight of flight configuration, including penalties for power, heat rejection and resupply.
- c. Availability within schedule.
- d. Cost.
- e. Volume of flight configurations.

Air and liquid lines shall be designed and routed to produce minimum flow resistance consistent with the test bed configuration.

Thermal integration shall be used to the extent consistent with the optimization criteria stated above. To minimize thermal protection requirements, thermal gradients shall be considered in equipment arrangement. Waste heat shall be considered for processes requiring a heat source.

Only components within the LSS shall be considered for multifunction use. Such use shall be considered only if it clearly will help attain optimization objectives.

2.6.3 INTERFACE DESIGNATION. The following components have functions in more than one subsystem.

<u>Thermal Control</u>	<u>Atmospheric Control</u>
Cabin air heat exchanger	H ₂ O electrolysis
Water separators in cabin air loop	Toxin burner
Equipment heat load simulators	Circulation fans and blowers
Air reheat heat exchanger	Air ducts and fittings
Heat transport liquid lines, fittings and pumps	CO ₂ concentration unit
	CO ₂ reduction unit
	Heat exchanger in CO ₂ reduction unit
	H ₂ O condenser-separator in CO ₂ reduction unit

Food, Water, and Waste Management

Food and water heaters and chillers

Humidity condensate collection, storage and purifying components

2.6.4 TEST OBJECTIVES. Tests shall be performed to evaluate the performance and reliability of components, subsystems, and the complete LSS. The details of the test objectives are presented in Section 7.

Component and subsystem tests shall have the following objectives.

- a. **Design Evaluation Tests.** Provide data for, and demonstrate adequacy of, component and subsystem performance, with particular attention to reliability and quality.
- b. **Assembly Tests.** Demonstrate performance of subsystem when assembled into working system units, prior to installation in the LSS test bed.

The following system tests shall be performed to examine system performance and reliability (including maintainability and crew safety elements).

- a. **System Checkout.** Conducted after installation of all subsystems in the test bed. The purpose is to ensure that all equipment is operational and responds properly to input signals.
- b. **Unmanned Tests.** Functional tests conducted on the completely assembled LSS. Simulated loads on the thermal and atmospheric control subsystem are introduced. The LSS is fully instrumented for internal and external display and readout.
- c. **Final Demonstration Test.** The final test before hardware delivery. Its purpose is to demonstrate the functional operation of the entire LSS to the NASA representatives.

2.6.5 CREW SAFETY. Crew safety shall be a major consideration in the design and development of the LSS. Identification of safety hazards and consideration of crew safety shall be undertaken in two categories: (1) functional hazards; and (2) nonfunctional hazards.

Functional hazards develop because of malfunctions in a process and are caused by equipment failures (LSS and other) or operator-induced failures.

Nonfunctional hazards continuously exist as a potential source of crew injury and/or equipment catastrophic damage. They result from operator interactions with problems in the design of the physical environment such as protruding beams and sharp corners.

Crew safety is the probability that the crew will be sustained at acceptable levels of performance capability during the specified mission or evacuation therefrom if and when occasioned by Category 1 hazards.

The equation for evaluating crew safety includes the following parameters:

- a. Reliability of the individual subsystems.
- b. Reliability of the elements of the applicable emergency system.
- c. Reliability of the switching functions required to replace the failing function.
- d. Probability that the failure mode of the subsystem will be catastrophic, destroying or otherwise preventing the capability to initiate emergency procedures or utilize emergency equipment.

The safety of the LSS shall be enhanced by the application of the following equipment design approaches.

- a. Identification of Category 1 hazards as part of the failure mode and effects analysis.
- b. Determination of the allowable durations of time for loss of each function for the various modes of failure identified.
- c. Quantification of the Category 1 crew safety figures of merit for each element of the design as part of the reliability analysis.
- d. Documentation (by checklist) of the Category 2 hazards, with the results evaluated in design review and, to the extent practicable, in system test.

2.6.6 RELIABILITY CONSIDERATIONS. System reliability shall be a major design consideration. Implementation of reliability features shall be documented in the Reliability and Quality Assurance Plan report.

Reliability shall be enhanced by the application of the following equipment design approaches.

- a. Employment of state-of-the-art subsystems and component approaches wherever consistent with the LSS program models.
- b. Continuous simplification of the component and subsystem interfaces and control circuits during the design phase.
- c. Reduction of redundancy, by using the human operator in all control and switching circuits.
- d. Minimizing the probability of interaction failures, as determined by failure modes and effects analysis, functional analysis, and comparative reliability analysis of candidate designs, including tradeoff comparisons with crew safety.

Reliability will be re-evaluated for possible changes of design during design review and at each of the system test program elements, including component acceptance testing, system assembly testing, and system evaluation testing.

During testing, the following activity will take place at either the supplier contractor facilities or at both. The work will be under the direction of the assigned engineer and will be evaluated by the project reliability engineer.

- a. Inspection of components specifically procured for LSS.
- b. Special inspections for designated items. (This inspection may include disassembly of the items.)
- c. Detailed failure analysis of all failed items.

Operational reliability will be maximized by development of operator procedures during system design and test; and development of rapid-access operator data for control and switching functions, including component repair. This will include customer operator training during contractor system tests and contractor participation in initial customer system operation.

2.6.7 DOCUMENTATION REQUIREMENTS. Operation manuals shall describe how to operate the equipment, including alternative operating modes for emergency conditions. Drawings, schematics and photographs as required shall be provided.

The following types of drawing will document the design and analysis activity.

- a. System study layouts showing alternative methods of performing a given function. These layouts will be informal and drawn primarily for the designer's use.
- b. Layout-type drawings showing design details for the manufacturing, installation, and inspection. The major emphasis shall be clarity and a minimum of drawings shall be generated.
- c. Photographs of wire harnesses, tubing, and instrumentation installations to document the final configuration in lieu of drawings.

SECTION 3

SUBSYSTEM EVALUATION

Tradeoff studies were used to select, size, and integrate the life support system for the minimum weight penalty consistent with mission requirements. The methods for evaluating the water reclamation equipment (Section 3.3) are typical of the tradeoff studies. The initial steps in the generalized procedure consisted of selecting promising candidate processes, establishing the weight penalty for independent operation, and preparing a relative rating chart based upon reliability, confidence, maintainability, and safety, as well as weight and power. Top candidates were re-evaluated for integrated operation.

3.1 THERMAL CONTROL

The thermal control system was designed to optimize the weight, power, and reliability of the life support system by thermally integrating the individual components with each other and with other spacecraft systems.

To accomplish this objective, three interrelated thermal control circuits were developed.

- a. The waste heat circuit, which conveys thermal energy from the power system to components having high-temperature bulk-heating requirements.
- b. The air circuit, which maintains a cabin air thermal environment conducive to the crew comfort while acting as an intermediate fluid in absorbing the net convected heat gain from components.
- c. A low-temperature coolant-fluid circuit, which absorbs heat from the air circuit, as well as directly cooled components, and rejects it to space through a radiator.

As a design requisite, it was assumed that the prototype electrical power would be generated by a dynamic power conversion system providing waste heat at 401°F through an intermediate heat transport fluid circuit. This power system was not installed in the test bed; the waste heat source was simulated by an externally located fluid heating and pumping unit.

A detailed analysis of the complete thermal control system is shown in Convair Report 64-26208, "Thermal Control Analysis for Space Flights of One Year Duration."

3.1.1 THERMAL AND ELECTRICAL CHARACTERISTICS. The thermal and electrical characteristics shown in this section are intended to reflect those of flight-qualified systems using current state-of-the-art techniques and hardware.

3.1.1.1 Power Conversion System. The electrical energy and waste heat capabilities of the prototype power conversion system were specified in Section 2.2.2.

3.1.1.2 Life Support System. Figure 3.1-1 shows the estimated thermal and electrical requirements for the life support system components and remaining spacecraft systems for the average design condition. The figure also summarizes these requirements for the maximum and minimum load design conditions.

The spacecraft systems other than life support consist primarily of electronic equipment used for tracking, communications, experiments, and spacecraft controls. A description of these components and their associated electrical energy requirements are given in Section 2.2.2. The thermal loads introduced by this equipment were simulated in the test bed by appropriately located electric, fluid, and air heaters.

3.1.1.3 Crew Metabolic Heat Loads. The following four-man-crew metabolic heat loads were used in establishing the design loads for this analysis. The wide range of values represents normal excursions due to scheduled daily rest and exercise periods.

<u>Activity Level</u>	<u>Crew Heat Load, Btu/hr</u>		
	<u>Sensible</u>	<u>Latent</u>	<u>Total</u>
Maximum (Exercise Period)	1172	1668	2840
Average (Daily)	820	1032	1852
Minimum (Rest Period)	566	791	1357

In addition, crew metabolic heat loads representative of the following two conditions were used in establishing off-design loads.

- a. Increased Crew. The crew is increased to three men for a period of three hours (during resupply).
- b. Increased Activity. The crew activity is increased to an emergency level corresponding to 450 percent BMR for a period of one hour.

The metabolic heat loads corresponding to these off-design conditions are shown below.

<u>Condition</u>	<u>Crew Heat Load, Btu/hr</u>		
	<u>Sensible</u>	<u>Latent</u>	<u>Total</u>
Increased Crew	1230	1548	2778
Increased Activity	1460	3096	5556

AVERAGE DESIGN CONDITION

ENERGY SOURCES (BTU/HR)		COMPONENT	ENERGY SINKS (BTU/HR)		
ELECTRICAL ENERGY	PROCESS HEAT		AIR CIRCUIT	COOLANT CIRCUIT	SPACE
1230	7000	CO ₂ CONCENTRATION UNIT	2980	5250	
1877	60	CO ₂ REDUCTION UNIT	1700	885	
		648 (REACTION) 2070			
3191		ELECTROLYSIS UNIT	285	836	
256		CATALYTIC BURNERS	256		
218	5760	WATER RECOVERY UNITS	300	5678	
210	85	FOOD MANAGEMENT (FREEZER & HEATER)	261		
20	120	WASTE MANAGEMENT	60		80
	35	PERSONAL HYGIENE (WASH WATER HEATER)	35		
1440		THERMAL CONTROL (BLOWERS, PUMPS, ETC)	1201	239	
410		INSTRUMENTS & CONTROLS	410		
6806		ELECTRONIC EQUIP. (SPACECRAFT)	2609	4197	
15,649	13,060	SUBTOTALS	10,097	17,110	80
MAXIMUM DESIGN CONDITION					
16,709	13,458		10,748	17,637	160
MINIMUM DESIGN CONDITION					
11,645	7,060		8,146	9,737	0

Figure 3.1-1. Thermal and Electrical Requirements

3.1.1.4 Cabin Wall Heat Flux. The thermal radiation exchange of the spacecraft cabin with the environment was calculated for the orbital elements and attitude program described in Section 2.2.2. These conditions are considered representative of earth orbit missions. Calculations were also made for an emergency mode in which attitude control fails and the cylindrical spacecraft acquires an end-to-sun orientation. Results of the analysis were used for thermal design of the cabin wall and radiator and to determine cabin wall heat flux.

The following criteria were used to select the optimum thermal characteristics of the spacecraft walls.

- a. The wall surface conditioning is to be uniform to compensate for the eventuality of failure in roll control and to simplify construction and fabrication.
- b. The surface conditioning should minimize the incident energy variations associated with loss in attitude control.
- c. The average orbital heat efflux through the cabin walls at the design attitude should equal the average daily crew metabolic heat load (1852 Btu/hr). This is required to provide tolerable cabin temperatures in the emergency case where, due to either power or system failure, the thermal control system cannot provide active heat rejection.
- d. The inside wall surface temperature shall not drop more than 5°F below the prevailing cabin air temperature. This restriction is required to ensure that humidity condensate will not form on the wall surfaces.

The Space Vehicle Radiant Energy Program developed at Convair for the IBM 7090 was used to evaluate the spacecraft incident energy flux for the design and emergency attitude modes. This analysis indicated that the energy absorbed by the spacecraft can be made fairly uniform for all attitudes by providing surface conditioning that will minimize the absorption of solar radiation. This can be accomplished by using currently available surface conditionings with a thermal emittance of 0.85 and a solar absorptance of 0.16. This conditioning would result in the vehicle average outside wall surface temperatures shown in Figure 3.1-2.

For a normal design attitude, a wall conductance of 0.016 to 0.022 Btu/hr-ft²-°R, depending upon radiator size and location, would permit the spacecraft to maintain passive control of the cabin air temperature if a failure in the thermal control system prevented active heat rejection. It would also limit the instantaneous wall surface temperature to a minimum value of approximately 4.5°F below ambient cabin air temperature.

3.1.1.5 Energy Balance. The spacecraft energy requirements, sources, and sinks are tabulated for the average design condition and are summarized for the remaining design and off-design conditions in Figure 3.1-3. Within this summary, the air

CONDITIONS: CYLINDRICAL SPACECRAFT
250 N. MI. CIRCULAR ORBIT
30° INCLINATION

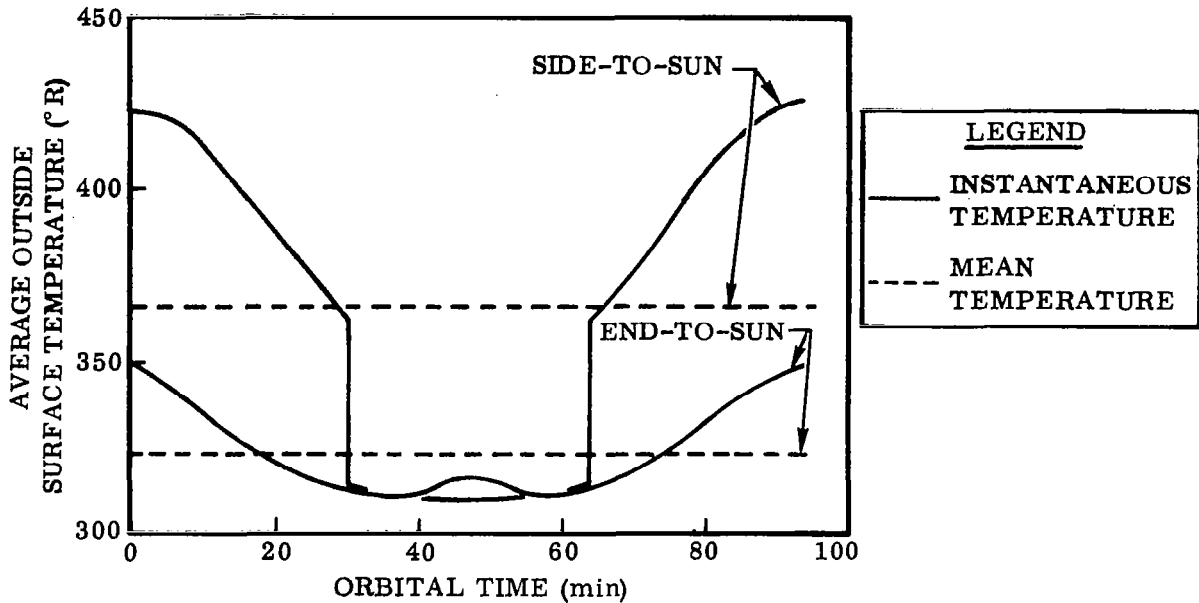


Figure 3.1-2. Spacecraft Outside Surface Temperature

circuit heat loads are broken down to show the amount of heat convected to the cabin air and the amount rejected directly into the duct system downstream of the cabin.

3.1.2 THERMAL CONTROL AIR CIRCUIT.

3.1.2.1 Temperature Restrictions. The air temperature leaving the cabin air-heat exchanger was limited to the range of 32-55°F to prevent the condensate from freezing in the heat exchanger or water separator and to prevent excessively moist air from entering the CO₂ concentration unit. (The unit draws air from the downstream side of the heat exchanger.) The heat-exchanger air inlet temperature was also limited to a maximum value of 150°F, which is compatible with the upstream electronic equipment convective cooling requirements.

3.1.2.2 Cabin Air Flow Rate. The minimum cabin air flow rates capable of independently satisfying the various system temperature and humidity requirements were calculated for the most severe combinations of sensible and latent heat loads and cabin air temperatures. These flow rates, as well as that required to assure a reasonable response under the maximum design heat load condition, are plotted as a function of heat exchanger exit air temperature in Figure 3.1-4. As shown, a cabin air flow rate of 820 lb/hr, with a corresponding heat exchanger air exit temperature of 40°F, is sufficient to satisfy all these requirements simultaneously. To this air flow rate must

AVERAGE DESIGN CONDITION								
ENERGY REQUIREMENTS, (BTU/HR)			COMPONENT	ENERGY SINKS (BTU/HR)				
METABOLIC	ELECTRICAL ENERGY	PROCESS HEAT		AIR		COOLANT CIRCUIT	CHEMICAL	SPACE
				CABIN	DUCT			
		13,060	LSS & SPACECRAFT SYSTEMS	4,623	5,474	17,110	1,422	80
	15,649							
1,852			CABIN (4150 CU FT)	1,852				
				-1,852				1,852
1,852	15,649	13,060	TOTAL (LATENT)	4,623 (1,032)	5,474	17,110	1,422	1,932
MAXIMUM DESIGN CONDITION								
2,840	16,709	13,458	TOTAL (LATENT)	6,122 (1,668)	5,614	17,637	1,622	2,012
MINIMUM DESIGN CONDITION								
1,357	11,645	7,060	TOTAL (LATENT)	2,553 (791)	5,098	9,737	822	1,852
EMERGENCY CONDITION NO. 1 - INCREASED CREW								
2,778	15,649	13,060	TOTAL (LATENT)	5,549 (1,548)	5,474	17,110	1,422	1,932
EMERGENCY CONDITION NO. 2 - INCREASED ACTIVITY								
5,556	15,649	13,060	TOTAL (LATENT)	8,327 (3,096)	5,474	17,110	1,422	1,932
EMERGENCY CONDITION NO. 3 - REDUCTION IN POWER & ACTIVE RADIATOR								
1,852	3,413	0	TOTAL (LATENT)	-621 (1,032)	1,653	1,103	0	3,130
LAUNCH CONDITION								
0	6,536	0	TOTAL (LATENT)	-765 (0)	2,268	3,181	0	1,852

Figure 3.1-3. Energy Balance Summary

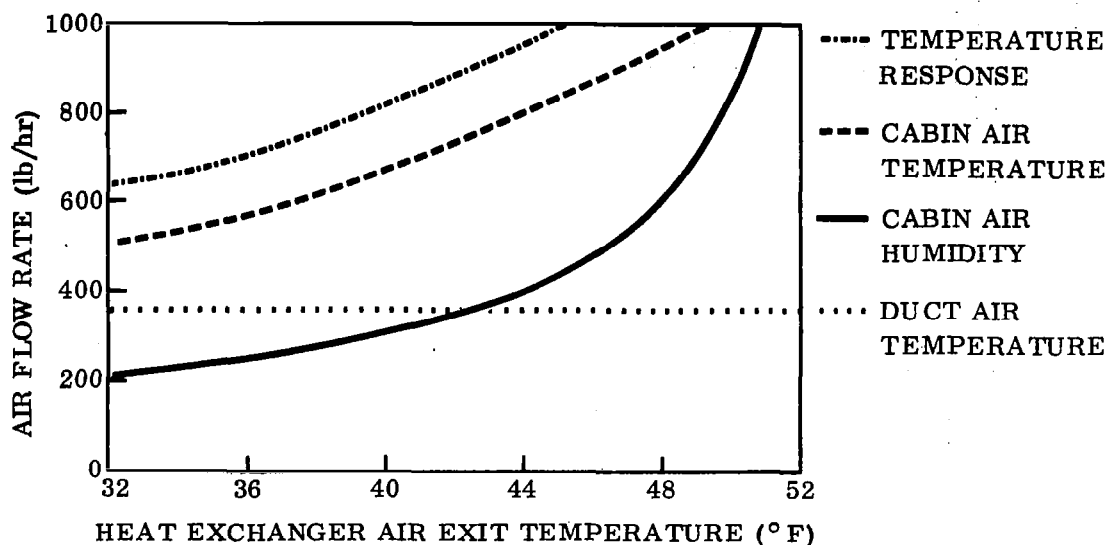


Figure 3.1-4. Airflow Rate Requirements

be added the air flow requirements of the components that short-circuit the main cabin air circuit: the CO₂ concentration unit (75 lb/hr) and the catalytic burners (5 lb/hr). The resultant total air flow rate used was 900 lb/hr.

3.1.2.3 Air Circuit Control. Various air conditioning schemes were systematically evaluated to determine which could best satisfy the circuit restrictions and requirements.

Independent cabin humidity and temperature control by two separate circuits was discarded because of redundant equipment and control requirements. Hence, only systems that simultaneously accomplish cooling and dehumidification were considered. These were the coolant bypass, reheat, and air bypass systems. Performance maps of the first two systems were developed; these are shown in Figure 3.1-5.

The coolant bypass configuration not only could not simultaneously satisfy the temperature and humidity restrictions, but also exceeded the maximum prescribed heat-exchanger air-exit temperature for cabin air temperatures higher than 68°F.

The reheat system could simultaneously satisfy these requirements as well as permit a limited degree of control over the relative humidity. However, the introduction of a reheat capability requires additional components and controls and hence reduces system reliability while increasing system weight and size.

The air bypass system introduces an alternate method of achieving a limited reheat capability. In this system, a thermostatically controlled bypass damper diverts a portion of the total air flow around the condensing heat exchanger to obtain a mixed downstream air temperature capable of satisfying the cabin cooling requirements. By so doing, it affords a means of temperature and humidity control without resorting to reheat, while delivering a substantially constant air quantity. However, to maintain the cabin relative humidity within the prescribed limits, the heat exchanger characteristics must be properly matched to the air circuit sensible and latent heat loads.

By means of a detailed analytical analysis, the maximum and/or minimum heat exchanger "heat transfer coefficient" requirements were established for numerous heat load conditions that impose the most severe tests of the circuit capabilities.

These coefficients were then normalized to a common air flow rate of 900 lb/hr and plotted as a function of coolant "WC" as shown in Figure 3.1-6. As indicated, a region of acceptable characteristics was found. Hence, this control system was selected for this application.

Figure 3.1-7 is a simplified schematic of the thermal control air circuit, indicating the locations of associated atmospheric and contaminant control subsystems.

3.1.3 THERMAL CONTROL LIQUID COOLANT CIRCUIT

3.1.3.1 Performance Requirements. The coolant fluid minimum temperature was set at 32°F to prevent water from freezing and damaging water-condensing life-support-system components. A maximum limit of 150°F, which was compatible with electronic equipment cold-plate cooling requirements, was used. Subsystems that cyclically exceed this maximum were designed to limit the maximum coolant exit temperature to that corresponding to a coolant vapor pressure less the minimum circuit operating pressure. This was to prevent the formation of vapor pockets in the coolant circuit.

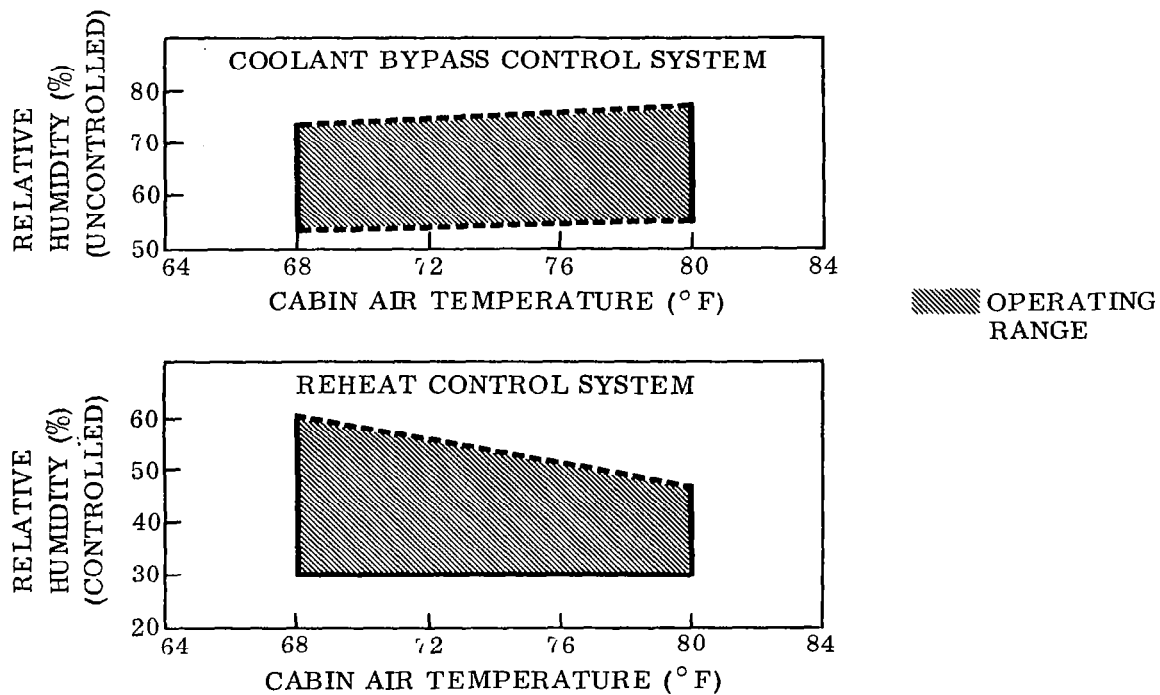


Figure 3.1-5. Performance Maps of Air Circuit Control System

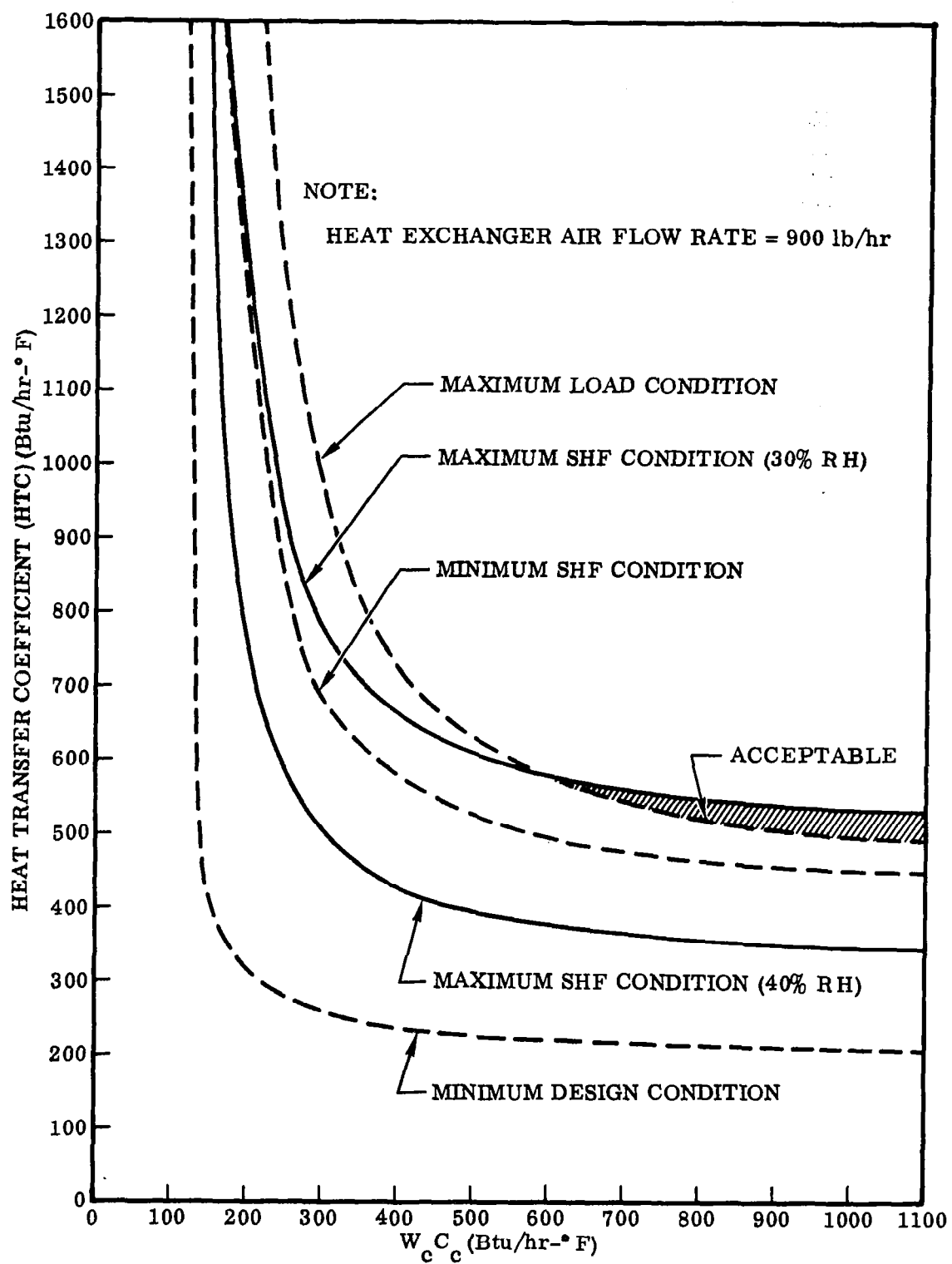


Figure 3.1-6. Heat Coefficient Requirements

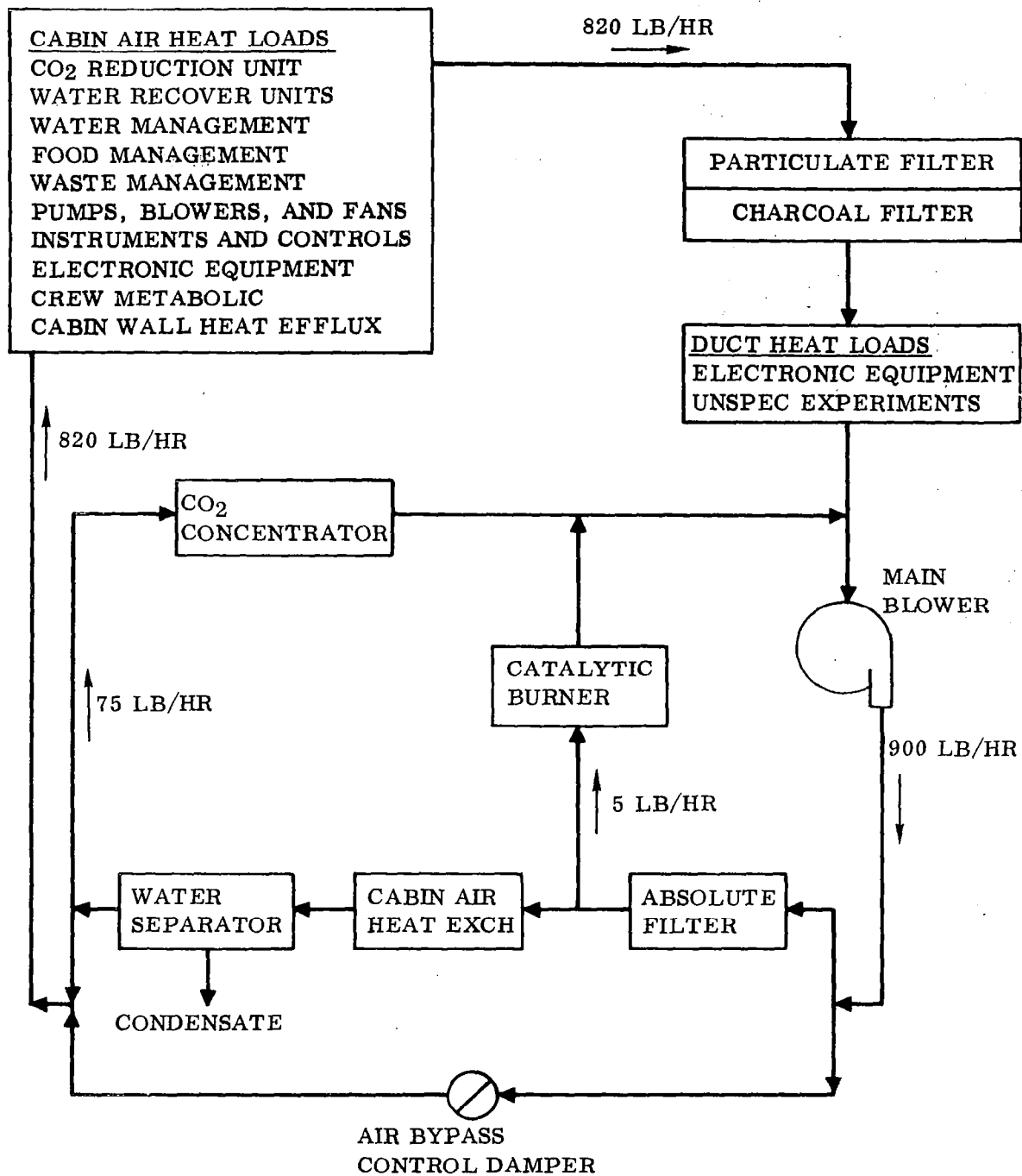


Figure 3.1-7. Thermal Control Air Circuit Flow Schematic

3.1.3.2 Heat Transport Fluid. Numerous fluids were systematically evaluated, using the following parameters.

- a. Toxicity.
- b. Explosiveness.
- c. Vapor pressure.
- d. Pour and freezing points.
- e. Corrosiveness.
- f. Chemical stability.
- g. Flash and fire points.
- h. Storage and handling problems.

Also considered were the thermophysical properties of specific heat, conductivity, viscosity, and density. These properties were simultaneously evaluated in the form of a "pumping power factor," which indicates the power required to achieve a prescribed rate of heat transfer.

Gases were eliminated from consideration because of their high pumping power factors. Similarly, a number of liquids (including some water solutions) that exhibited pumping power factors significantly higher than those of the remaining liquids were excluded. Still others were rejected because of explosive and/or combustible characteristics or high freezing points.

The laminar pumping power factors of the remaining liquids as a function of temperature are shown in Figure 3.1-8. Inspection of this figure indicates that ethylene glycol would be very desirable. However, ethylene glycol is toxic if ingested and was discarded because of the possibility of inadvertent leakage of coolant into potable water in the various heat exchangers throughout the system.

FC-75, a new fluorocarbon produced by the 3-M Company, was selected for evaluation because of its desirable pumping power factor, excellent low-temperature characteristics, and nonflammability.

3.1.3.3 Distribution System. The distribution system shown in Figure 3.1-9 was selected as the combination best suited to satisfy the component thermal requirements as originally established. Modifications were made to this distribution system to accommodate subsequent changes in component and/or subsystem thermal requirements.

The cabin air heat exchanger, water chiller, and CO₂ reduction unit all require low-temperature coolant for condensing or chilling operations. Hence, these units were located in parallel circuits immediately downstream of the radiator. The

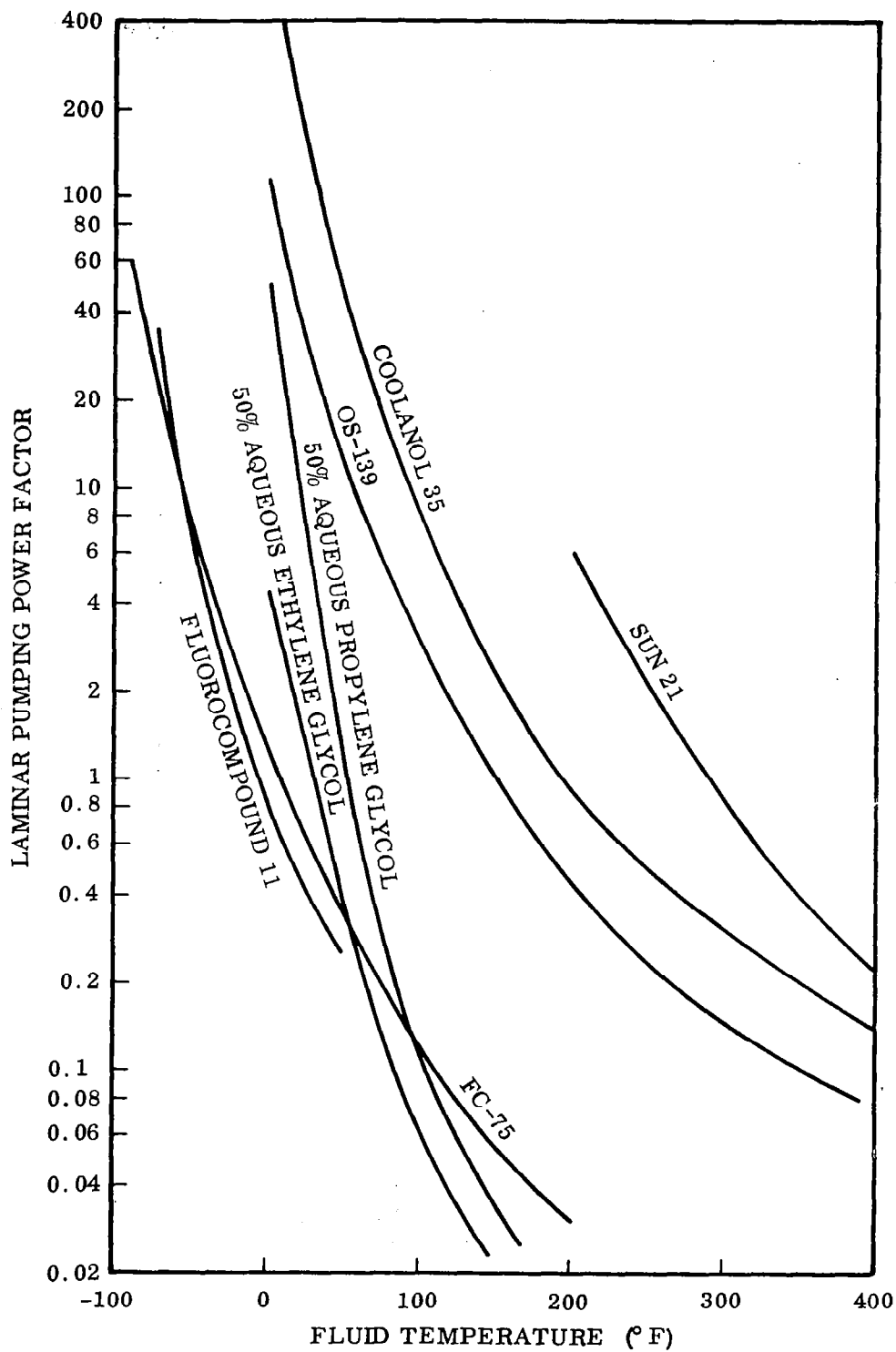


Figure 3.1-8. Heat Transport Fluid Characteristics; Laminar Pumping Power

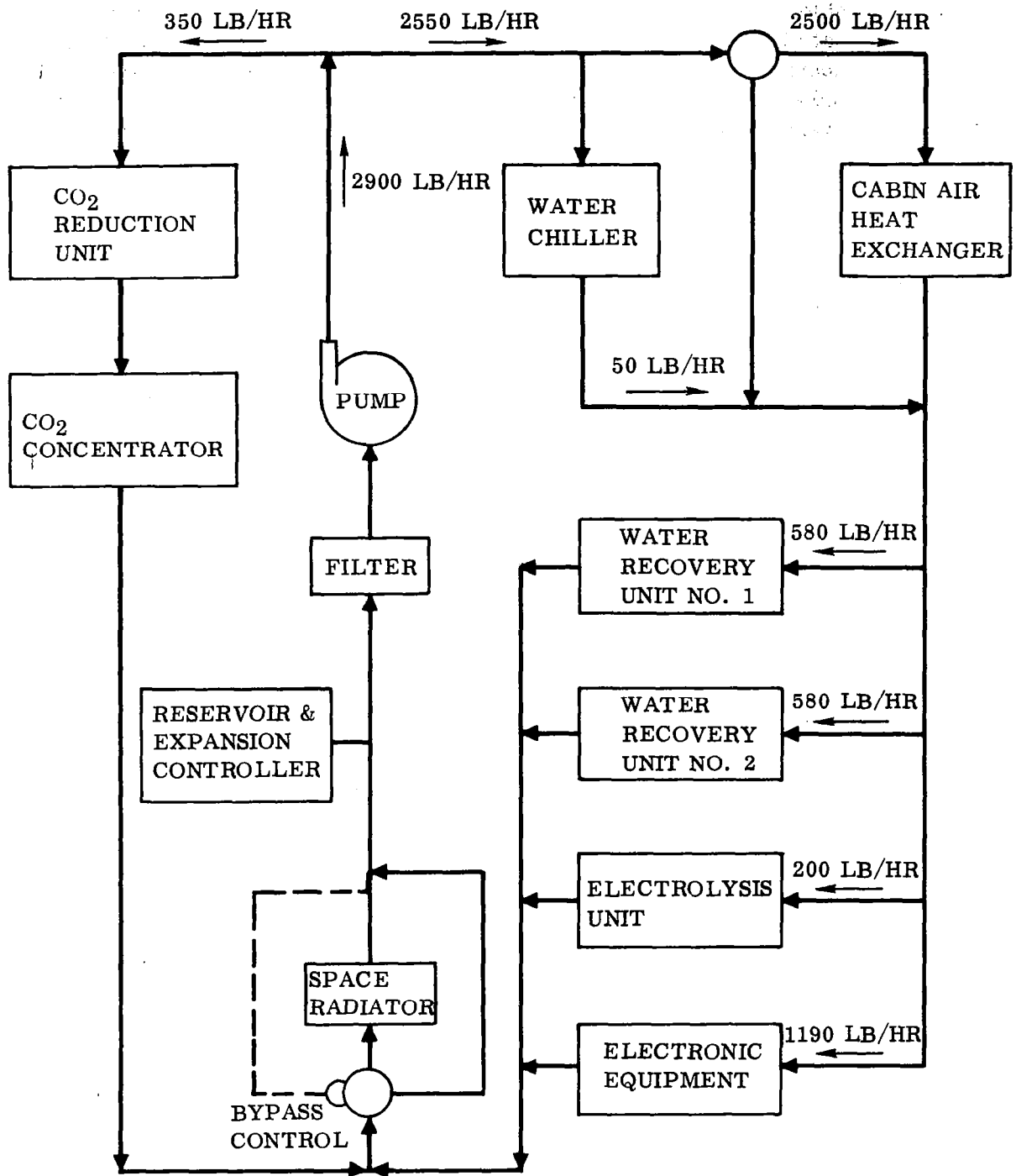


Figure 3.1-9. Liquid Coolant (FC-75) Flow Diagram

remaining components were located in a series-parallel arrangement downstream of the low-temperature units. This permits each component to receive coolant at the lowest available temperature without increasing the total fluid flow rate above that required to satisfy the cooling requirements of the low-temperature units. In this way, the temperature difference between the coolant stream and the heat sources is increased, and a maximum rate of heat transfer per unit area results. This permits the size and weight of the heat-transfer devices in each component, as well as the radiator, to be minimized.

Components whose functions are interdependent or that are located close to one another were placed in common coolant circuits, when possible, to minimize the length of fluid lines. The CO₂ concentration unit, which has a large cyclic cooling requirement, was placed at the end of the branch circuit to minimize its effect upon the remainder of the system.

Although not shown in the schematic, balancing devices should be installed as required throughout to ensure proper fluid distribution. Each component should also be provided with an internal or external means of coolant fluid bypass to permit individual units to be turned off or cycled without significantly affecting the coolant rate in the rest of the circuit.

3.1.4 RADIATOR ANALYSIS AND DESIGN. The radiator analysis and design were undertaken to ensure compatibility with other components in the thermal control circuit.

3.1.4.1 Design. Two radiator configurations were considered: (1) longitudinal radiator tubes and (2) circular radiator tubes.

An analysis of the instantaneous absorbed energy distribution around the vehicle cylindrical surface (in the normal side-to-sun orientation) showed lateral gradients on the surface throughout the entire orbit. This absorbed energy distribution is shown in Figure 3.1-10 for the midsolar and midumbra positions. Hence, if the radiator were oriented with its tubes parallel to the cylindrical elements, wide variations in absorbed energy would prevail between tubes at different circumferential positions. This would introduce a continuous control problem, which would be magnified in the event of loss in roll control.

Therefore, it was decided to use a radiator configuration having circumferential cooling tubes. With this configuration, the heat absorbed by the radiator from the space environment is averaged over the circumference.

The approach and analysis used in arriving at the tube size, number, and spacing are discussed in detail for a typical application of this nature in Appendix 3 of Con-vair Report 64-26208, "Thermal Control Analysis for Space Flights of One Year Duration."

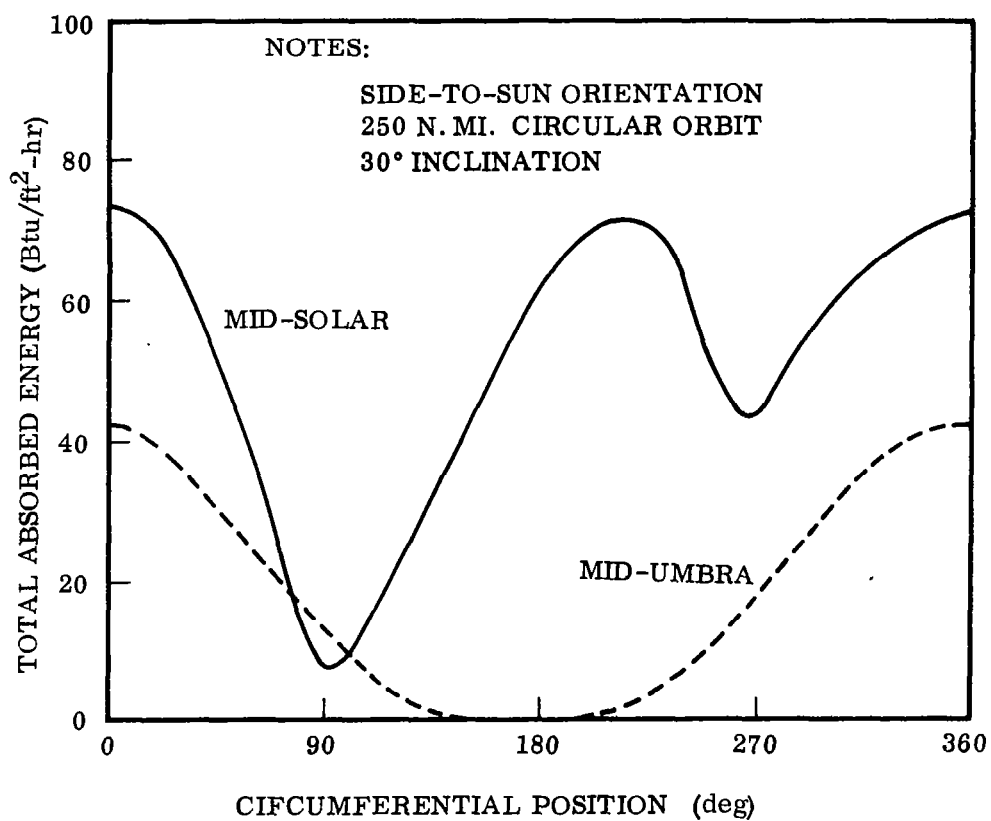


Figure 3.1-10. Absorbed Energy Distribution Around Cylinder

3.1.4.2 Radiator Control. A number of techniques could be used to control the radiator fluid discharge temperature to the prescribed $32 \pm 2^\circ\text{F}$ for the varying absorbed-space-heat conditions. Those considered for this application are listed below.

<u>Technique</u>	<u>Method of Control</u>
Active Area Regulation	Thermally isolate excess radiator sections.
Makeup Heat or Reheat	Add heat to coolant loop from secondary source.
Flow Regulation	Change coolant flow rate.
Fin Effectiveness Regulation	Change spacing of effective tubes.
Coolant Bypass	Divert part of coolant flow around radiator.

Active area regulation was discarded because it would permit the stagnant coolant in the thermally isolated tubes to freeze.

The makeup or reheat techniques would require large quantities of heat for the control function under low internal load. The only source of heat in the quantity required is from the power system. However, since this source would not be available in the event of a power system failure, it was also discarded.

Flow regulation would require variable flow pumps and would subject the LSS components to cyclic flow variations. Because it would also increase the complexity of the component thermal controls, it too was rejected.

The control scheme selected was a combination of fin effectiveness regulation and coolant bypass. Stepwise temperature control is attained by varying the number of active tubes while bypassing the excess fluid through an internal bypass valve. An essentially constant coolant flow rate is thereby maintained. Through proper design, the active tubes provide sufficient conductive heat transfer to adjacent inactive tubes to prevent the stagnant coolant from freezing.

Figure 3.1-11 is a schematic of the proposed system. Typical orbital performance data is shown in Figure 3.1-12 for the normal side-to-sun orientation.

3.1.4.3 Space Radiator Simulator. For the test bed application, no attempt is made to duplicate the cyclic performance of a space radiator. Rather, a simple refrigerant unit is used to remove heat from the coolant fluid and return the fluid to the test bed at $32 \pm 2^\circ\text{F}$. A thermal image of the space radiator system will thus be presented to the remaining system.

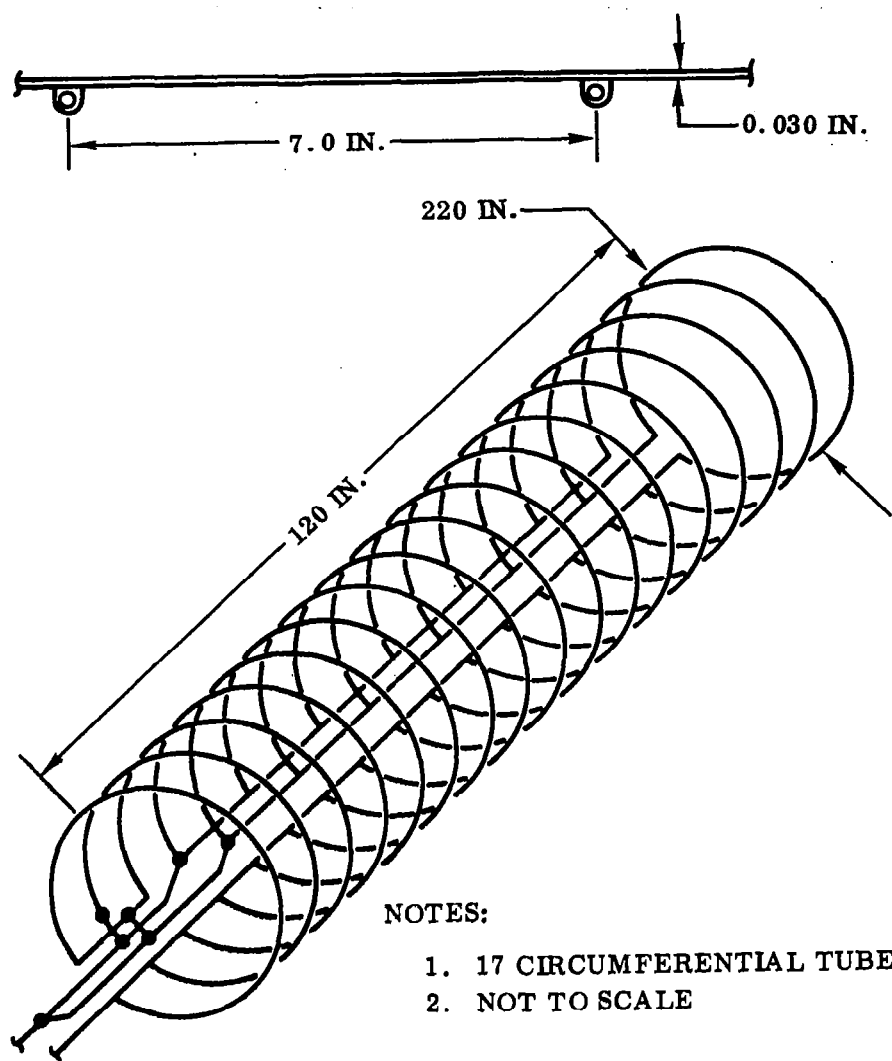


Figure 3.1-11. Space Radiator Tube and Fin Configuration

3.1.5 WASTE (PROCESS) HEAT CIRCUIT

3.1.5.1 Performance Requirements. The process heat circuit must absorb heat at 401°F from the power system through an intermediate heat-transport-fluid circuit and deliver it to the LSS at a minimum 375°F.

3.1.5.2 Heat Transport Fluid. Many heat transport fluids capable of prolonged operation without degradation were evaluated with the same parameters used in the selection of liquid coolant circuit fluid (paragraph 3.1.3.2).

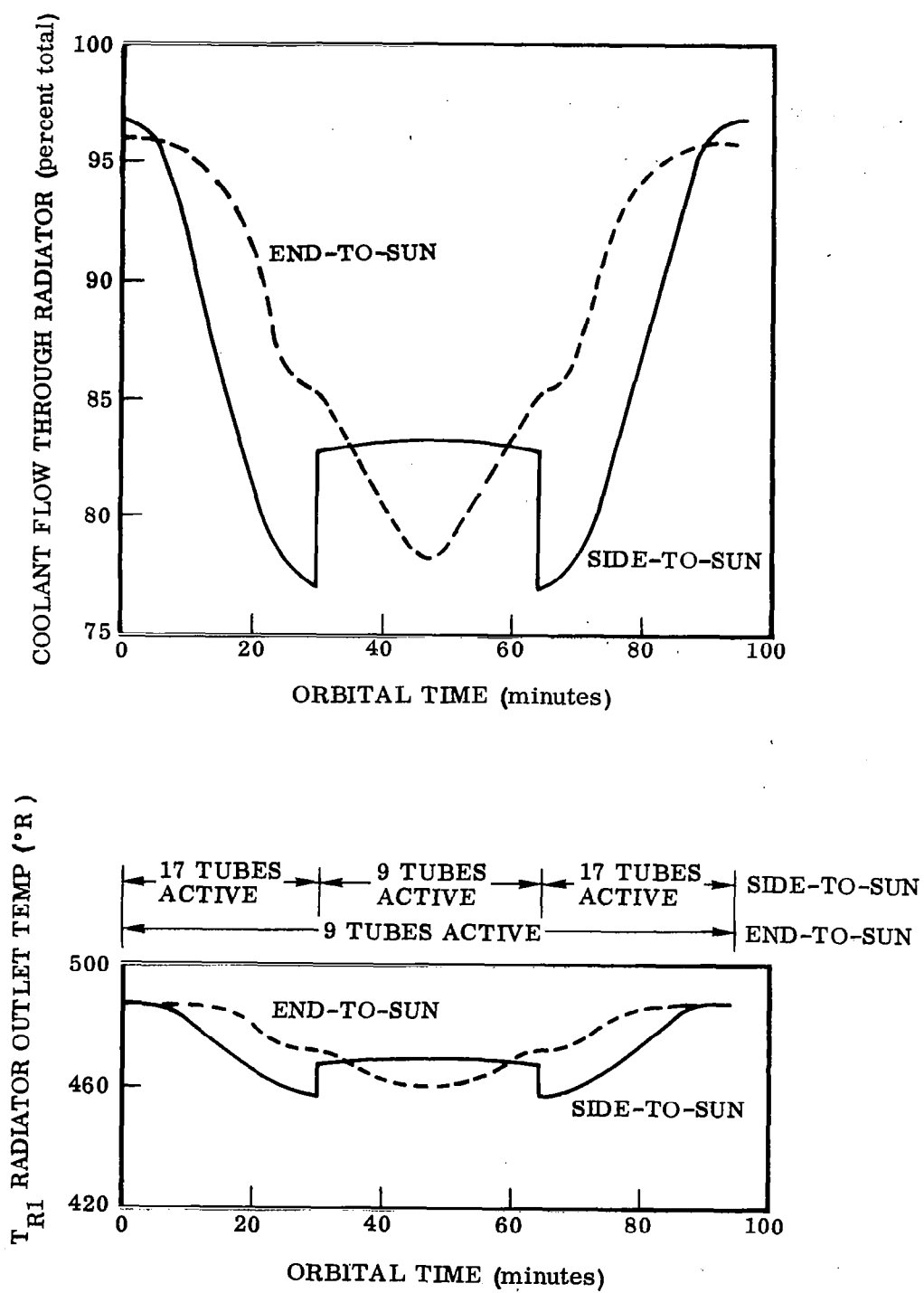


Figure 3.1-12. Typical Radiator Performance

DC-331, a silicone fluid produced by the Dow Corning Company, exhibited the most suitable characteristics of the fluids studied.

3.1.5.3 Distribution System. The distribution system shown in Figure 3.1-13 was selected as the combination best suited to satisfy the original component bulk heating requirements. Modifications were made to this system to accommodate subsequent changes in component and/or subsystem thermal requirements.

In this circuit, all LSS components that operate essentially full time are interconnected in a common branch circuit. Components requiring the highest fluid temperatures are located upstream of the others. Where possible, components were placed adjacent to one another in a common branch circuit to minimize the length of fluid lines and the associated heat loss to the cabin air circuit.

The CO₂ concentration unit, having high cyclic heating requirements, was isolated in a separate branch circuit to minimize its effect upon the rest of the system.

Although cryogenic stores heat exchangers were not installed in the test bed, provisions were made for them in the design. These heat exchangers would be located in yet another branch circuit. Under an emergency repressurization requirement, the total heat transport fluid flow rate could thus be diverted to the stores to obtain the high heat transfer rate required to accomplish this task in a reasonable length of time.

Here too, as in the coolant circuit, balancing valves, orifices, and bypass lines must be provided to ensure proper fluid distribution and to permit the units to be turned off or cycled without significantly affecting the heat transport fluid flow rate in the rest of the circuit.

3.1.5.4 Power System Simulator. No attempt was made to duplicate the power conversion system or intermediate heat transport fluid circuit for the test bed application. Rather, a waste heat source external to the test bed was used to simulate the prototype system and provide fluid, at the required flow rate, to the LSS at a temperature of 375°F. Thus, a thermal image of the power conversion system is presented to the rest of the LSS.

3.2 ATMOSPHERIC CONTROL

3.2.1 CO₂ CONCENTRATION UNIT

3.2.1.1 Techniques Considered. The CO₂ concentration techniques selected for study were: adsorption on zeolite bed; adsorption by solid amine; adsorption by silver oxide; and electrodialysis. Other methods were also investigated but were not considered

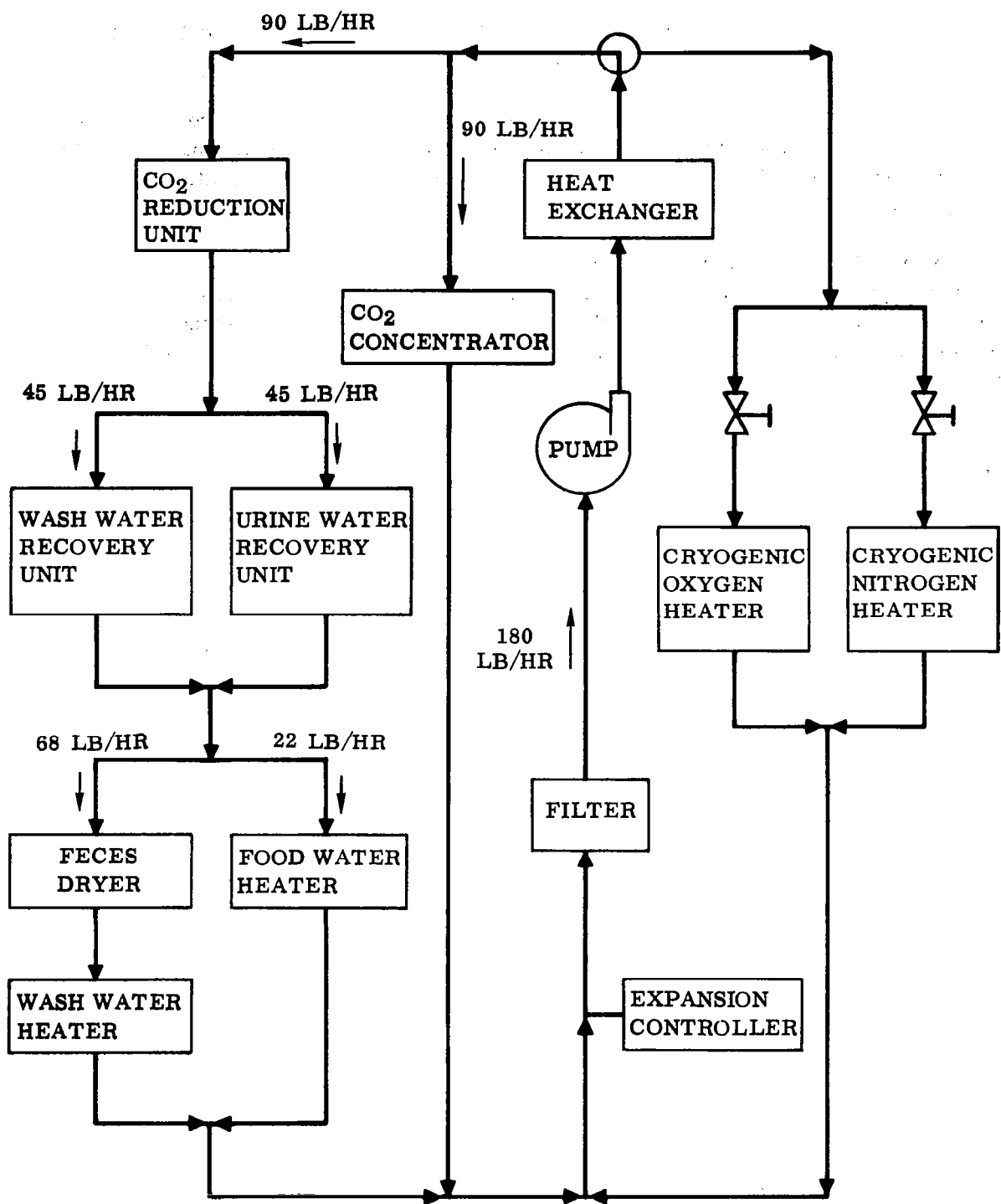


Figure 3.1-13. Process Heat (DC-331) Flow Diagram

applicable. A detailed discussion of specific methods studied is presented in Convair Report 64-26203, "Oxygen Regeneration Recovery System Evaluation for Space Flights of One Year Duration."

Information on the four techniques was obtained from several manufacturers and from the literature.

Zeolite Bed. The CO₂ removal technique that has had the most development effort is the solid adsorbent technique using regenerable synthetic zeolite. In general, the regenerative zeolite units use a separate water-adsorbent bed upstream of the zeolite. Such water adsorbents as zeolite or silica gel have been used, but because of its lower desorption energy requirement, silica gel is preferred by most manufacturers.

The schemes studied employed two or more adsorbent beds and functioned cyclically in the adsorbing and desorbing modes. Process air is taken into the unit and dried to a low dew point (less than -70°F) in the water-adsorbing bed. The CO₂ is then removed from the process stream in the zeolite bed. The beds are heated or cooled as required through either the process stream or additional fluid circuits. Figure 3.2-1 is a simplified flow schematic.

The ability of this system to remove residual cabin air from the zeolite canisters prior to desorption is not well defined at this time. Adequate removal of this air is required for collection of high-purity CO₂.

Solid Amine System. The solid amine CO₂-removal system uses solid absorption beds of silica gel (approximately 85 percent), ethylene glycol, and solid salts of amino acid. This system appeared to be somewhat simpler than the zeolite system, since a single bed was used to absorb both water and CO₂. Three beds cycling through the cooling, absorbing, and desorbing phases were proposed. Desorption was accomplished by heat and low pressure (25 mm Hg). Figure 3.2-2 is a flow schematic.

It was claimed that this system was more desirable than the zeolite system because of the weight saved by elimination of separate water-adsorbing beds. However, solid amines have achieved a capacity of 0.5-1.0 percent CO₂ by weight compared with 4-6 percent for the zeolites at a CO₂ partial pressure of 3.8 mm Hg. Since the desorbent effluent contains water vapor as well as CO₂, a dehumidifier and water collection would be required to prevent subsequent O₂ regeneration processes from being penalized. The possibility of decomposition of the amines would require the use of low pressure to reduce the required desorption temperature below the decomposition temperature.

Silver Oxide System. At the time of this evaluation, a silver oxide CO₂ concentration unit was being built for NASA/LRC. This unit consisted of two beds that cycled between adsorption and desorption and contained the required auxiliaries and controls for operation. The system weight was estimated at 300 pounds and the power

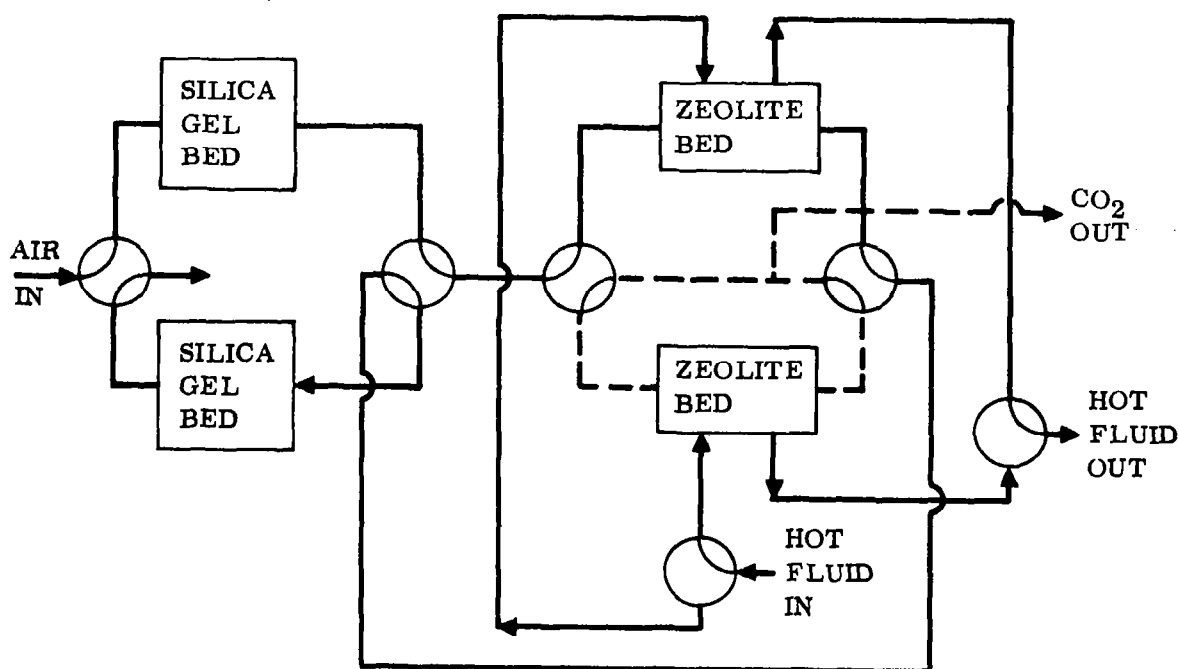


Figure 3.2-1. CO₂ Concentration Unit Simplified Schematic

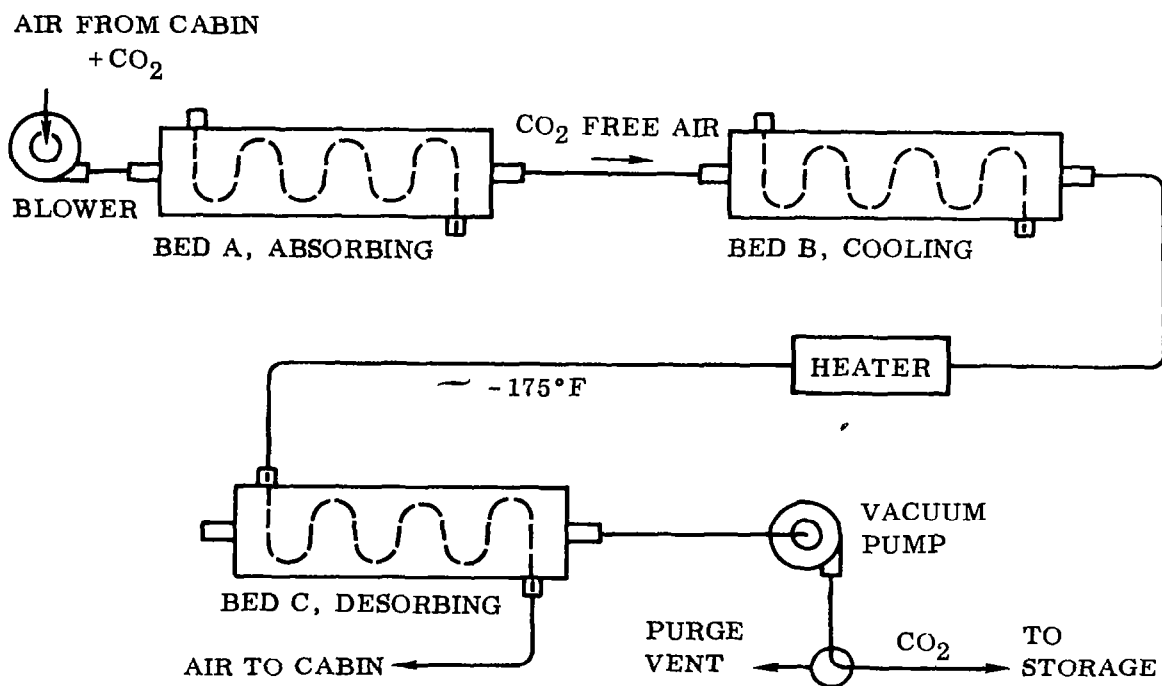


Figure 3.2-2. Proposed Solid Amine System

requirement at 1500 watts for four men. Although system improvements were anticipated, it was estimated that their incorporation and the investigation of present problems would require at least one more year. Therefore, the system was not considered further for the LSS.

Electrodialysis. This technique was claimed to separate CO_2 from air at an efficiency of about 50 percent while electrolyzing enough water to supply about 40 percent of the metabolic O_2 requirement. The technique would require a number of modules connected electrically in series but with gas and liquid streams connected in parallel. The modules consist of a number of cells containing ion-exchange resins. The cells are divided by anion or cation selective membranes.

In operation, moist cabin air containing CO_2 is forced through the absorber cell, where the CO_2 reacts with hydroxyl ions to form carbonate and bicarbonate ions. The carbonate and bicarbonate ions are driven electrically through the cation-selective membrane into the concentrator cell, where they react with hydrogen ions to re-form CO_2 plus water. The CO_2 is then separated from the water. The primary mode of heat rejection is through use of excess water flow through the cells, with circulation through an external heat exchanger. A means of humidifying the entering process air stream and a mechanism for liquid-gas separation are needed.

3.2.1.2 Technique Selected. Adsorption on zeolite was determined to be the most practical technique. The silver oxide system was not evaluated extensively because its development was not sufficiently advanced. The solid amine system was rejected primarily because of the low maintainability, high system weight (including power penalty), and large volume. The electrodialysis system was rejected on the basis of anticipated low reliability and the possible hazard of membrane rupture.

Information derived from and evaluated during these studies is presented in Tables 3.2-I and 3.2-II. Table 3.2-III presents the ratings of the systems.

3.2.2 CO_2 REDUCTION

3.2.2.1 Techniques Considered. Four basic systems were evaluated: (1) Bosch reaction; (2) Sabatier reaction, with and without methane decomposition; (3) solid electrolyte process; and (4) molten electrolyte (Li_2CO_3) process. Information on these systems was obtained from manufacturers and the literature. In some cases, the same basic concept was being investigated by several firms, and the quoted system properties differed. The characteristics used in the evaluation were, for the most part, engineering estimates based on laboratory data. A nominal daily metabolic requirement for four men of 8.0 pounds of O_2 and 9.0 pounds of CO_2 was included in the preliminary criteria for comparison purposes. (See Table 3.2-IV.)

Some water electrolysis system and weight penalties were included in the systems in order to compare the water-producing and oxygen-producing reactions.

Table 3.2-I. CO₂ Concentration Techniques

UNIT	VOL- UME (ft ³)	WEIGHTS				NOTES	
		POWER (avg)		FIXED UNIT	OTHER		TOTAL
		watts	lb @ 290 lb	WEIGHT (lb)	WEIGHTS (lb)		WEIGHTS PENALTY (lb)
Molecular Sieve	1+	260	76	65	20 ⁽⁴⁾	179.5 ⁽⁵⁾	1. Assuming CO ₂ purge.
Hamilton Standard		300 ⁽³⁾	87 ⁽³⁾		9.5 ⁽¹⁾		
					9.0 ⁽⁸⁾		2. Weight of dehumidi-
					10 ^(3, 8)	276.5 ⁽⁶⁾	fier and water separator.
Molecular Sieve	2	300	87	80	9.5 ⁽¹⁾	186.5 ⁽⁵⁾	3. Additional power re-
Tapco		300 ⁽³⁾	87 ⁽³⁾		10 ⁽⁸⁾		quired if waste heat is
					10 ^(3, 8)	283.5 ⁽⁶⁾	not available for use.
Solid Amine	4	260	76	152	19 ⁽²⁾	256 ⁽⁵⁾	4. Modification weight to
MRD		360 ⁽³⁾	104 ⁽³⁾		9.0 ⁽⁸⁾		convert from vacuum
					12 ^(3, 8)	353 ⁽⁶⁾	desorption to thermal
							desorption.
INDICATED TEST DATA (BEST RUN)							
Electrodialysis	2	1417	410	97 + 2.8 lb O ₂ /day	Subtract	366	5. Total weight if waste
					15 lb and	36 ⁽⁸⁾	heat is available for
					345 watts	+19.5 ⁽⁷⁾	use.
					for O ₂ credit	421.5	6. Total weight if waste
					PROPOSED (OPTIMISTIC)		
Ionics	2	560	162	65 + 3.12 lb O ₂ /day	Subtract	93.5	7. Accessory weights.
					16.7 lb and	5.0 ⁽⁸⁾	
					384 watts	19.5 ⁽⁷⁾	8. Heat rejection penalty.
					for O ₂ credit	118.0	

Table 3.2-II. Reliability Problem Summary Chart

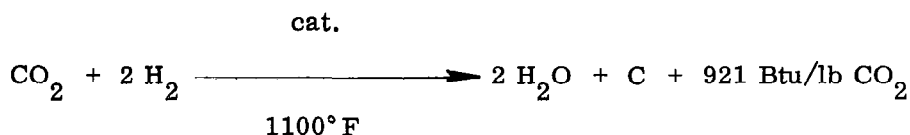
	SOLID AMINE	MOLECULAR SIEVE	ELECTRODIALYSIS
Controls component reliability	Rotating seals both difficult to develop and operate. Motor, bearings, and timer involved.	Valve and timer complexity. Large number of operations, sequences critical.	Water flow control somewhat complex and sensing difficult.
Canister (bed) integrity	Internal structure complicated by cycling arrangement.	Compacting and powdering.	Membrane rupture.
Over-all subsystem	Transfer of fluids and electrical inputs to rotating elements.	Large number of connectors and components in cycling and sequencing operations.	Manifolding for fault isolation and "repair" very complex.
Repairability	Inherent requirement for "sealed" module.	Spares requirements high.	Isolation of cell module. Identification of failed item.
Safety	Not significant.	Not significant.	Membrane rupture.
Process controllability	Not critical.	Not critical.	Critical flow and pressure requirements. Process variability.

Table 3.2-III. Rating Chart, CO₂ Concentration Unit

	MOLECULAR SIEVE	SOLID AMINE	ELECTRO- DIALYSIS
Reliability	1	2	3
Maintainability	2	3	1
Safety	1	1	2
Availability	Yes	Yes	Yes
Total Weight (Hardware, power, & heat rejection)	280 lb	353 lb	118-451 lb
Volume	1.5 ft ³	4.0 ft ³	2.0 ft ³
Confidence	1	2	3

Notes: Ratings are in the order of ranking. Availability is based on vendor estimates. Confidence is based on Convair appraisal of potential to develop satisfactory system on schedule.

Bosch Reaction Systems. Bosch systems are based on the following reaction in the presence of an iron catalyst.



The equilibrium conversion of CO₂ to steam is not complete; it depends upon the temperature and the relative abundance of the products of the primary and secondary reactions. The following secondary reactions may represent 30-98 percent of the recycle load necessary for complete conversion.

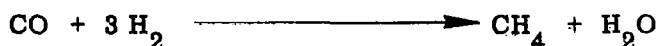
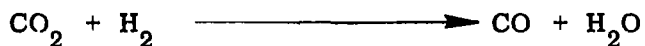
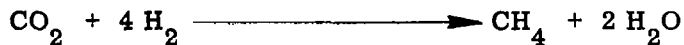


Table 3.2-IV. Estimated CO₂ Reduction Subsystem Characteristics

Assumptions: 4 men; 8 lb/day of O₂; 9 lb/day of CO₂; no CO₂ concentration capacity included; pure CO₂ assumed.

SUBSYSTEM	VOLUME (ft ³)	WEIGHT		POWER (watts)	REMARKS (See below)
		(lb)	(lb/day)		
Bosch			(Expend- able)		
1. Tapco (Reference 9) (includes electrolysis)	3.3	100	1.64 (H ₂ O)	1205	1, 2, 3, 9
2. MRD (No electrolysis included)		125	1.64 (H ₂ O)	500	3, 8
Sabatier					
1. MRD	2.2	54	0.64 (H ₂) 2.0 (H ₂ O)	75	3, 4
2. Isomet Reactor Only	0.6	8	---	0	5
3. Sabatier System Estimate, Including Acetylene Formation from CH ₄		239	1.64 (H ₂ O)	2265	6
Solid Electrolyte					
1. Estimate		194	0.23 (Catalyst) 1.45 (O ₂)	1275	
2. Isomet System (Reference 15)	36	200	0.14 (Catalyst)	3000	7
Molten Electrolyte Lithium Carbonate System	8	200	1.45 (O ₂)	1500	

Remarks:

1. Catalyst plus structural support weight included at 40 lb for one year. Actual usable catalyst is about three quarters of this, or about 30 lb.
2. Wick-type electrolysis included at about 24 lb and 900 watts.
3. H₂O used for oxygen makeup.
4. 95% overall efficiency assumed.
5. Start-up power = 250 watts.
6. Integrated Ionics CO₂ scrubber and H₂O electrolysis unit included at 200 lb and 1790 watts.
7. Undeveloped and not available for subject LSS (Reference 15).
8. Catalyst included = 8 lb. Useful life not stated but suggested at possibly 3 months.
9. Volume of 3.3 ft³ assumes a packing factor of 2.

According to the literature, at 1025°F, 30 percent conversion has been obtained. The net reaction has been reported to be fairly insensitive to pressure variations around one atmosphere, because the competing side reactions tend to eliminate any advantage gained by pressure changes.

The basic Bosch system schematic shown in Figure 3.2-3 is based on preliminary data from MRD and Tapco. Ideally, the Bosch reactor is fed pure CO₂ and H₂. The process of reaction, cooling, condensation, water separation, and recycling produces H₂O and carbon. Since the noncondensable reactor gases are continually recycled in the system, it is important not to introduce N₂ to the reactor from the CO₂ concentrator or the cabin air. This factor favors a positive pressure on the CO₂ concentration and storage system as well as on the reactor loop itself. (Of course, contamination of the cabin air with reactor gases favors a negative pressure in the reactor.) A positive pressure would tend to eliminate N₂ leakage (and also O₂ and water vapor leakage, which represents a loss in efficiency) into the system. A small amount of N₂ leakage into the reactor loop could be controlled by a periodic or continuous bleed purge. Since a purge to vacuum would cause a gas loss, purge through a catalytic burner and back into the cabin is preferred. Fairly high N₂ concentrations have been estimated to be acceptable; Tapco indicated that 20 percent N₂ could probably be tolerated.

NOTE: FLOWS SHOWN ARE FOR FOUR MEN FOR ONE DAY

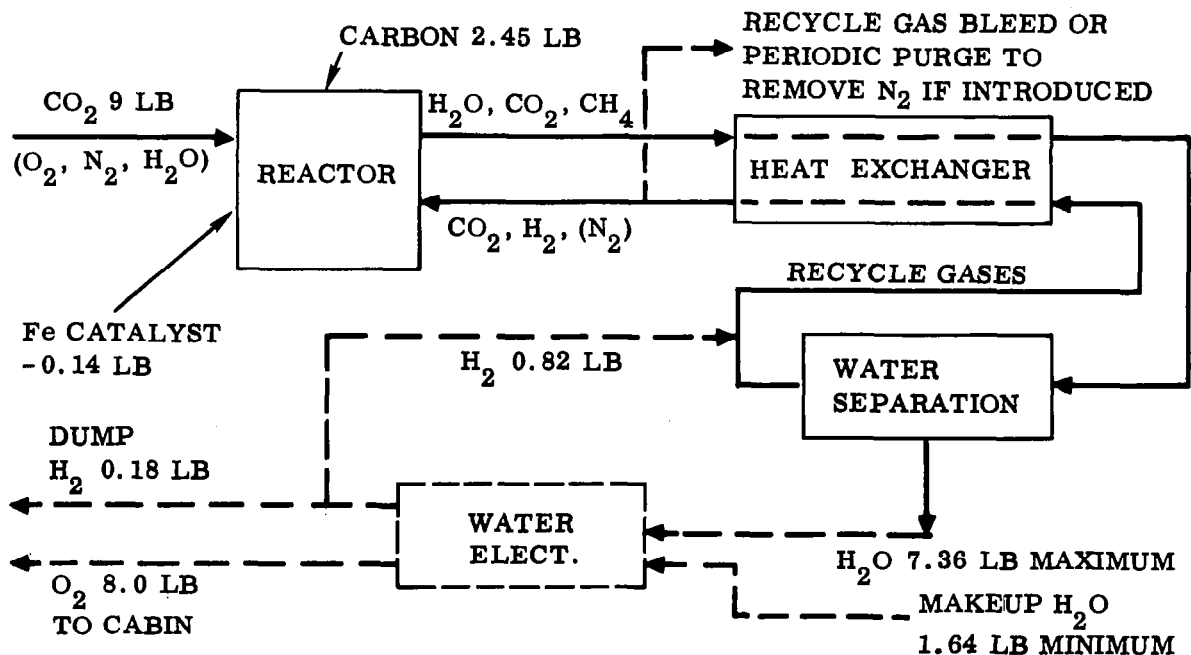


Figure 3.2-3. Bosch Reaction System

The major problem with the Bosch system is carbon removal. The carbon is sooty, magnetic, and quite messy to handle. MRD proposed periodically blowing the soot free of the catalyst as well as confining it to the desired reactor area by means of electromagnets. The Tapco design continually scrapes the carbon loose and transports it by means of the recycle gas flow to a regenerable stainless steel filter.

The carbon-to-catalyst consumption ratio for the reaction has been reported from about 2 to 200. Both MRD and Tapco indicated that 20 was easily attained. MRD estimated that the ratio was more nearly 100 in the tests of its Bosch reactor. A ratio of about 20, as indicated in Figure 3.2-3, was used in the weight tradeoffs.

Tapco Bosch System. Figure 3.2-4 is the Tapco Bosch system schematic. The system weights in Table 3.2-V are those received from Tapco; weights were modified to satisfy the specific requirements of the CO₂ reduction unit for the LSS.

The Tapco reactor is a stainless steel cylindrical shell housing iron-disk catalyst plates about 1/8 inch thick and about 1/2 inch apart. The disk assembly revolves at 1 rpm, and the carbon is removed from the disks by a set of scraper prongs extending from the side of the cylinder. The reactor is fed CO₂, H₂, and hot recycle gases. An electrical heater in the reactor provides additional heat to the entering gases to maintain a reaction temperature of 1200°F. From the center inlet manifold of the reactor chamber, the gases flow radially outward, and carbon is deposited on the catalyst disks. The gas flow through the reactor picks up loosened carbon and transports it out of the reactor.

The recycle gases and suspended carbon particles then pass to a stainless steel filter. The filter is too heavy to discard but is required because of the high temperature of the reactor gases. A filter blowdown loop was proposed by Tapco to clean the filter. After the loaded, off-line, stainless steel filter cools down, the carbon is blown into an expendable lightweight filter. Tapco proposed the integration of this blowdown procedure into the cabin air recirculation loop. In this way, the cabin recirculation blower could be used for open-loop carbon blowdown; the air flow through the carbon might remove trace contaminants and eliminate the need for an activated charcoal bed.

From the on-line stainless steel filter, the reaction products flow through a diversion valve to either the regenerative heat exchanger or the recycle blower. Gas is routed to the blower only if carbon transport by the gas flow through the reactor to the filters is not adequate. The recycle flow rate is about seven times that of the net inflow of CO₂ and H₂, sufficient for carbon transport; no diversion of gases to the blower is necessary.

The recycle gases pass through the heat exchanger, are cooled, and then pass to the condenser separator. There they are cooled below the dew point of the contained water vapor by coolant from the heat rejection system. The condensed water vapor

Table 3.2-V. Tapco Bosch System Weight, Volume, and Power Breakdown

COMPONENT	WEIGHT (lb)	VOLUME (ft ³)	POWER (watts)
CO ₂ Reduction Reactor*	53	0.6	195
Carbon Filters	8	0.35	
Compressor (Blower)	3	0.07	70
Condenser-Separator	2	0.03	
Electrolysis Unit	24	0.10	900***
Instrumentation & Controls	5		40
Heat Exchanger	5	0.50	
Total	100	1.65**	1205

* Includes thermal insulation and 40 lb for catalyst assembly.

** Assuming a packing factor of 2.0, the volume is 3.3 ft³.

*** Given in Reference 8 as 800, but revised to 900 after personal communication with Tapco representative L. Hoffman.

is separated from the noncondensable recycle gases by the action of a porous, metallic, capillary plate. The separated water passes to the water electrolysis system, and the cool recycle gases re-enter the heat exchanger to cool the hot gases from the reactor. From the heat exchanger, the recycle gases mix with the incoming CO₂ and H₂ and then are passed back to the reactor by means of the blower. Waste heat may be used to heat the incoming CO₂ and H₂ to conserve electrical heater power, which would otherwise be required.

The initial weights estimates by Tapco are indicated in Table 3.2-V. The reactor weight includes about 40 pounds of iron catalyst, structure, and insulation. The carbon filter weight does not include the blowdown system (blower, ducting, expendable filters, etc.). Integration of this system with the cabin air circulation system was probably assumed by Tapco. The electrolysis unit weight is also lower than is presently found in electrolysis system designs.

MDR Bosch System. Figure 3.2-5 is the MRD Bosch system flow schematic. The weights presented by MRD were later adjusted for system comparisons. The reactor is cylindrical, with iron catalyst strips running parallel to the flow. After passing by

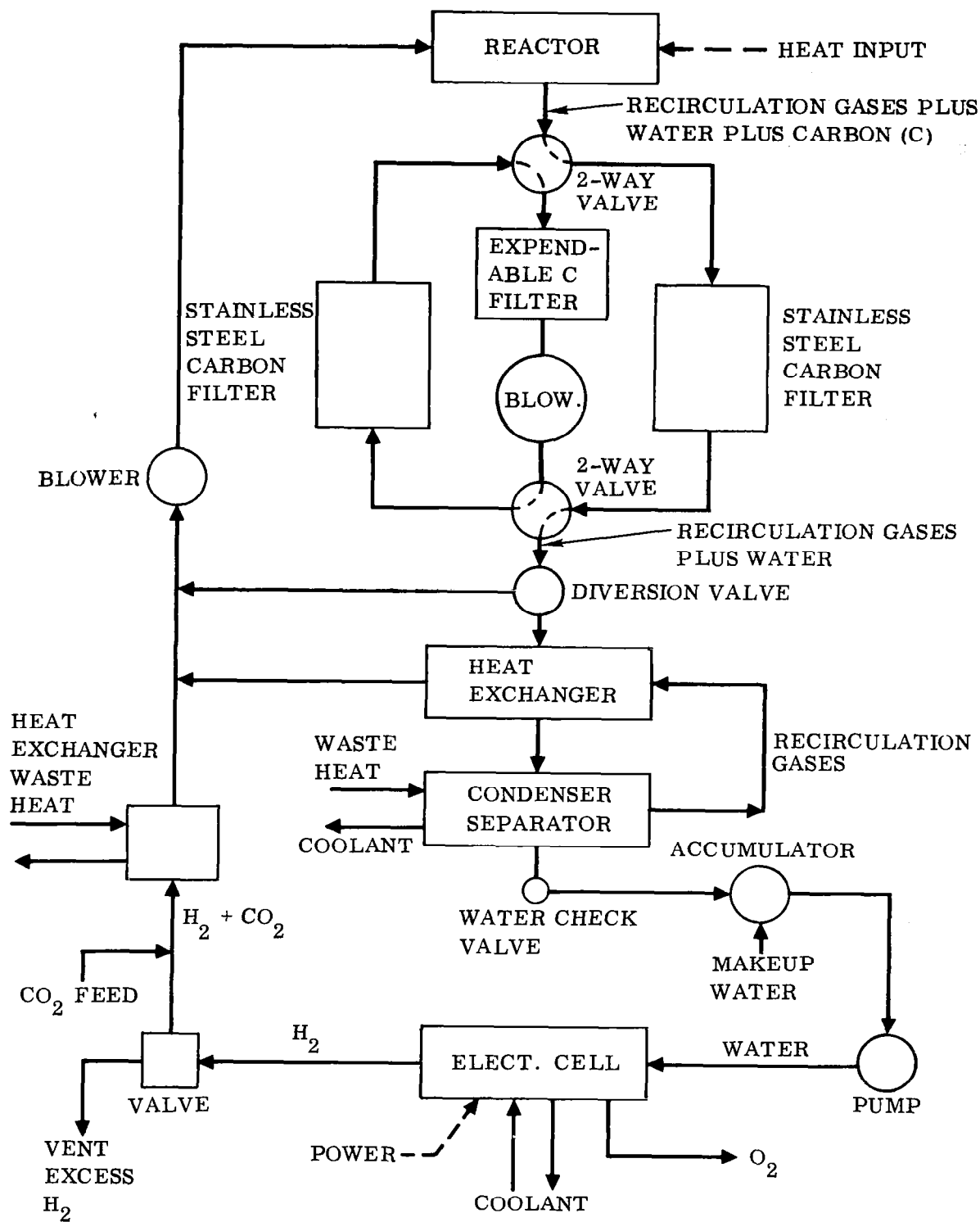


Figure 3.2-4. Tapco Bosch CO₂ Reduction System Flow Diagram

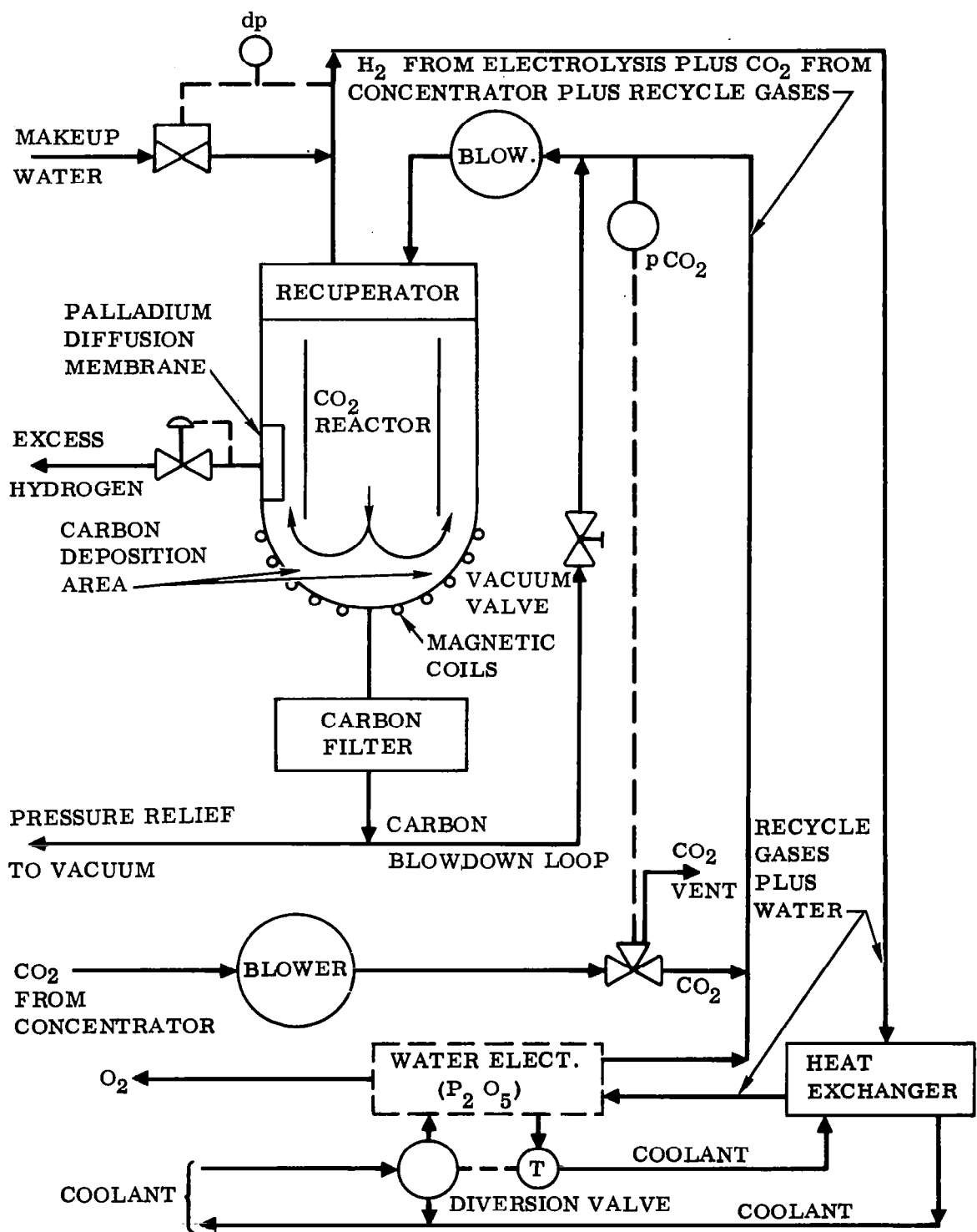


Figure 3.2-5. MRD Bosch CO₂ Reduction System Flow Diagram

the catalyst, the gases flow by the bottom section of the reactor, which includes an electromagnet for carbon collection. The reactor is designed so that the recycle gas temperature in this region is below the Curie point of the ferritic carbon particles (about 700° F).

The hot gases next flow through the recuperator, where they are cooled by the incoming recycle gases. They are further cooled by the liquid-to-gas heat exchanger before they are passed to the electrolysis unit.

MRD proposed the use of P_2O_5 for both electrolysis and gas-liquid separation; hence, no gas-liquid separator is required in the system, and the hydrogen evolved from electrolysis merely re-enters the recycle gas stream, where it is used to react with CO_2 . If P_2O_5 electrolysis were not used for electrolysis, a gas-liquid separator would be needed, and different flow paths would be required.

The incoming CO_2 in the MRD system is mixed with the recycle gases and then passed back to the reactor through a blower. The CO_2 inlet flow is controlled by the partial pressure of CO_2 in the recycle loop. When CO_2 is not needed, it is vented back to the cabin. This inefficiency could be eliminated by a CO_2 accumulator.

Makeup water is introduced directly into the recycle gases and transported to the electrolysis unit to yield the required metabolic oxygen. The hydrogen resulting from the electrolysis of this makeup water tends to build up in the reactor loop and is vented to space by the use of a palladium diffusion membrane. This membrane is exposed to the recycle mixture but only passes hydrogen as a function of the pressure on the vacuum side of the membrane (for a constant reactor pressure). The amount of H_2 in the reactor evidently can be controlled by merely maintaining a given pressure on the vacuum side.

For carbon removal from the reactor, a blowdown loop is used. Periodically, the reactor is shut down and the electromagnet is turned off. The blower circulates the recycle gases through the reactor and carbon filter loop to blow the carbon from the reactor into an expendable filter.

An estimated weight breakdown for the MRD Bosch system is given in Table 3.2-VI. The weights were estimated for a flight system in about 1967, not a currently deliverable system.

Sabatier Reaction Systems Without Methane Decomposition. The Sabatier systems are based on a reaction that produces methane and do not require any carbon removal. The reaction, considered by many for advanced applications, is written

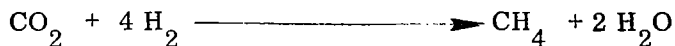


Table 3.2-VI. MRD Bosch System Weight and Power Breakdown
(Flight Model)

COMPONENT	WEIGHT (lb)	POWER (watts)	
		NORMAL	EMERGENCY
Reactor	40		
Heater	2	400	400
Electromagnet	5		
Catalyst	8		
Carbon Collector (Filter)	10		
Insulation	20		
Heat Exchanger	10		
Palladium Diffuser	5		
Manifolds and Piping	10		
Recycle Blower	10	75	90
Controls	5	25	25
CO ₂ Sensor	4	5	5
Totals	129	505	520

The reaction requires suitable catalysis for low-temperature operation and avoidance of undesirable side reactions such as the formation of carbon which proceeds at about 1000°F. Nickel and ruthenium have been considered as possible catalysts. The Sabatier reaction evolves 1640 Btu/lb of CO₂ reacted.

A basic flow schematic for a Sabatier system is shown in Figure 3.2-6. No recycle is used, and the noncondensable products of the reaction are vented overboard. The result of this jettisoning is the loss of both carbon and hydrogen from the spacecraft. Since the carbon comes from food that would be stored as an expendable for a mission duration suitable for the Sabatier system, the loss of carbon is not important. Hydrogen dumped overboard in the form of methane, however, requires makeup. Storage of this hydrogen is a major problem and introduces large weight and volume penalties.

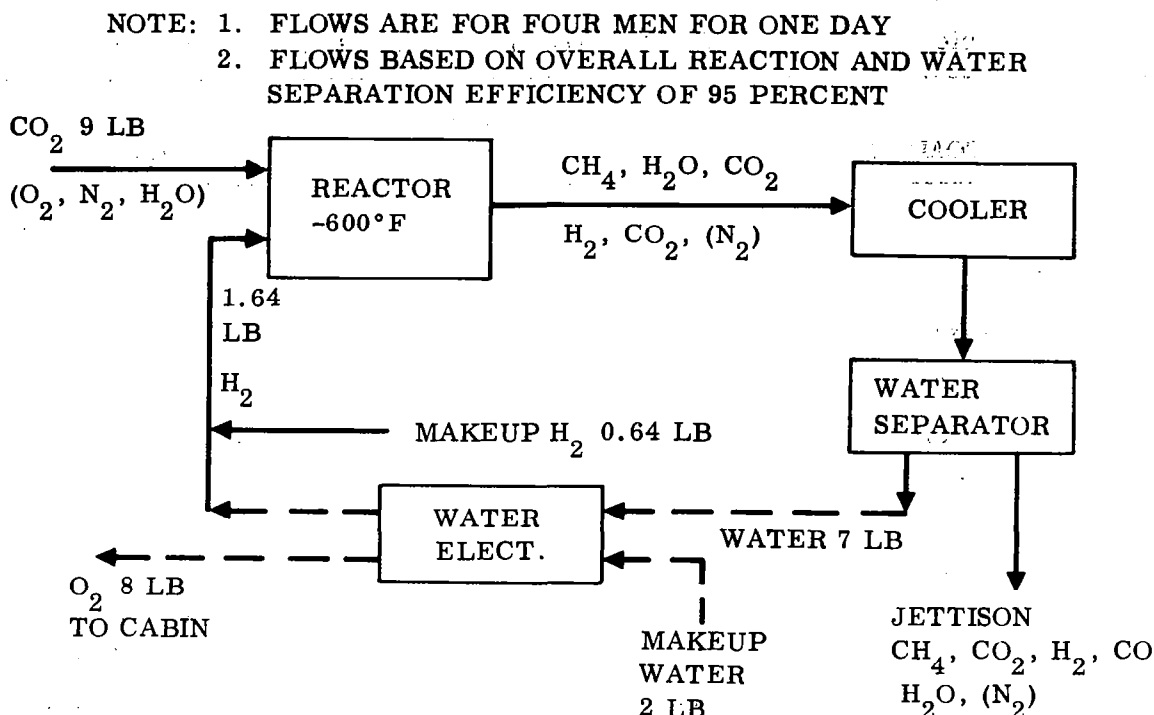


Figure 3.2-6. Sabatier Reaction System

In addition to the methane dumped overboard, some unreacted H_2 and CO_2 will be dumped as well as some unseparated or uncondensed water. These losses constitute another important weight tradeoff consideration and depend on the reactor conversion efficiency and water condenser-separator efficiency. Achievable conversion efficiencies of 90-99 percent have been reported in the literature. Since efficiencies of water removal are around 99 percent, the overall efficiency for calculating gas losses in the Sabatier system was taken as 95 percent.

As in the Bosch system, the purity of the CO_2 introduced to the reactor is quite important. Oxygen and water introduced cause inefficiencies, and any N_2 introduced is lost directly overboard. The catalyst consumption is reportedly very low, and thus no weight penalty is indicated.

MRD Sabatier System. The MRD Sabatier system flow schematic shown in Figure 3.2-7 is fairly typical. A weight breakdown is given in Table 3.2-VII. Hydrogen and carbon dioxide are fed into the reactor-mixing manifold by means of pressure regulators and fixed orifices.

Table 3.2-VII. MRD Sabatier System Weight and Power Breakdown

COMPONENT	WEIGHT (lb)	POWER (watts)
Reactor	14	60 (for start-up only)
Insulation	10	
Heat Exchanger	6	
Feed and Discharge Regulators	9	
Water Separator	3	15
Pressure and Temperature Indicators	4	
Tubing, Piping, and Mounting Frame	8	
Totals	54	15 (continuous)

All the hydrogen discharged from the electrolysis unit passes through a regulator and fixed orifice into the reactor. Similarly, CO₂ is fed to the reactor through a regulator, which is controlled by the quantity of hydrogen available from the electrolysis unit. No hydrogen makeup is included in the MRD system, and the resulting excess CO₂ would be jettisoned with the noncondensable gases. If hydrogen storage were desired, the makeup hydrogen could be introduced upstream at the H₂ regulator. In this case, the regulator, which can be manually set, would be adjusted so as to introduce approximately stoichiometric amounts of CO₂ and H₂ to the reactor.

Cabin gas is used to cool the Sabatier reactor as it generates excess heat that cannot be completely carried off by the products of the reaction because of the low system flow rates. These products are cooled in the heat exchanger, by means of a liquid coolant, to a temperature below the dew point of the water vapor present. The liquid water is separated from the noncondensable reaction products in a centrifugal water separator. The noncondensable gases, such as N₂, CO₂, CO, and H₂, are vented overboard, and the condensed water is diverted to water storage and indirectly to the water electrolysis unit. These flows are controlled by back-pressure regulators that also control the pressure in the reactor. Since the water flowing into storage from the water separator is not sufficient to provide for all the water flow to the electrolysis unit, makeup is required from expendable water stores or from the water reclamation system.

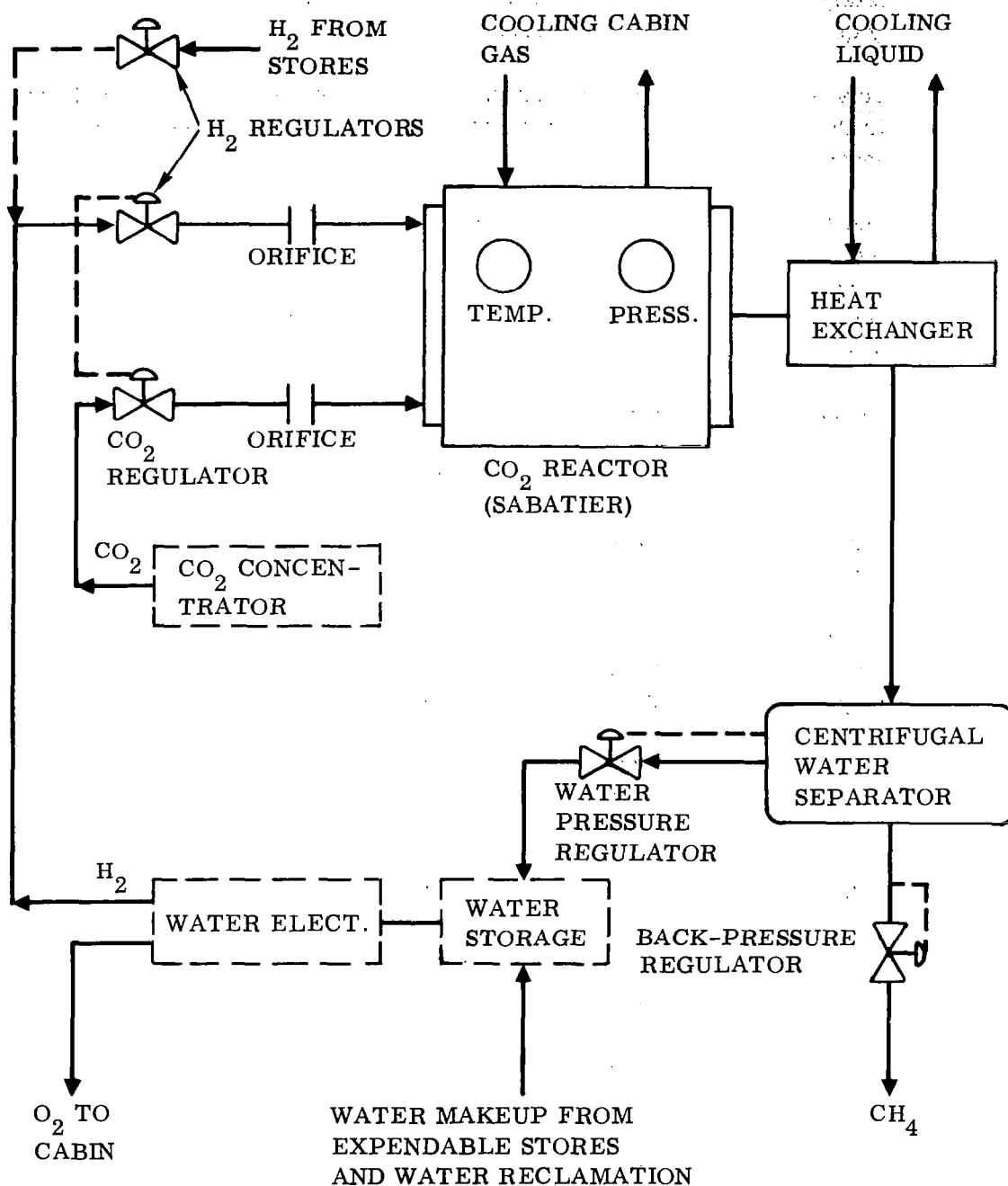


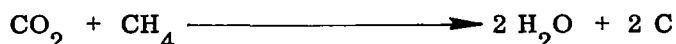
Figure 3.2-7. MRD Sabatier CO₂ Reduction Unit Flow Diagram

The Sabatier reactor proposed by MRD is shown in Figure 3.2-8. Carbon dioxide and hydrogen enter the reactor and flow past the start-up heater. The gases then flow over the hot catalyst ($\sim 600^\circ\text{F}$) and react to form H_2O and CH_4 . The reactor conversion efficiency quoted by MRD for the system was 90-95 percent.

Sabatier Systems With Methane Decomposition. To eliminate the hydrogen makeup requirement in the Sabatier system, various techniques for methane decomposition have been proposed.

One scheme forms acetylene (C_2H_2) and H_2 in an electric arc furnace. The H_2 is separated by a palladium filter and is recycled to the Sabatier reactor. Carbon formed in the arc process presents a handling problem and also tends to short out the arc. Power consumption was estimated to be 400 watts, which is quite high. In addition, the system has not been developed to any extent.

Another technique utilizes the net reaction

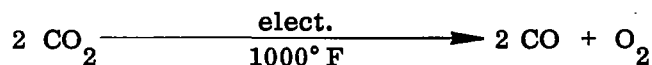


The carbon removal is again a problem. Essentially, the Bosch reaction is being accomplished in two steps.

The pyrolysis of CH_4 directly to C and H_2 was also considered. This method, however, requires a temperature of about 2000°F . Furthermore, the carbon formed is evidently very hard, and its removal from the pyrolyzer would be difficult.

All the techniques for methane decomposition appear to be in early stages of development and not applicable to the subject LSS. No techniques that appeared to offer any ultimate advantage over the Bosch system were reviewed.

Solid Electrolyte System. A solid electrolyte system can be postulated, based on the net reaction



In order to reclaim all, rather than just half the oxygen, as above, a catalytic reactor would also be included to convert CO to carbon and CO_2 . If the reactor is not included, oxygen necessarily dumped as CO constitutes a large weight penalty. If, on the other hand, the reactor is included, carbon removal and catalyst consumption problems similar to the Bosch system accrue. Estimates on carbon-to-catalyst consumption range from 10 to 100, similar to the Bosch system.

The system requires a high power level for the high-temperature electrolytic cell, and makeup oxygen is required as indicated in Figure 3.2-9. It may be supplied

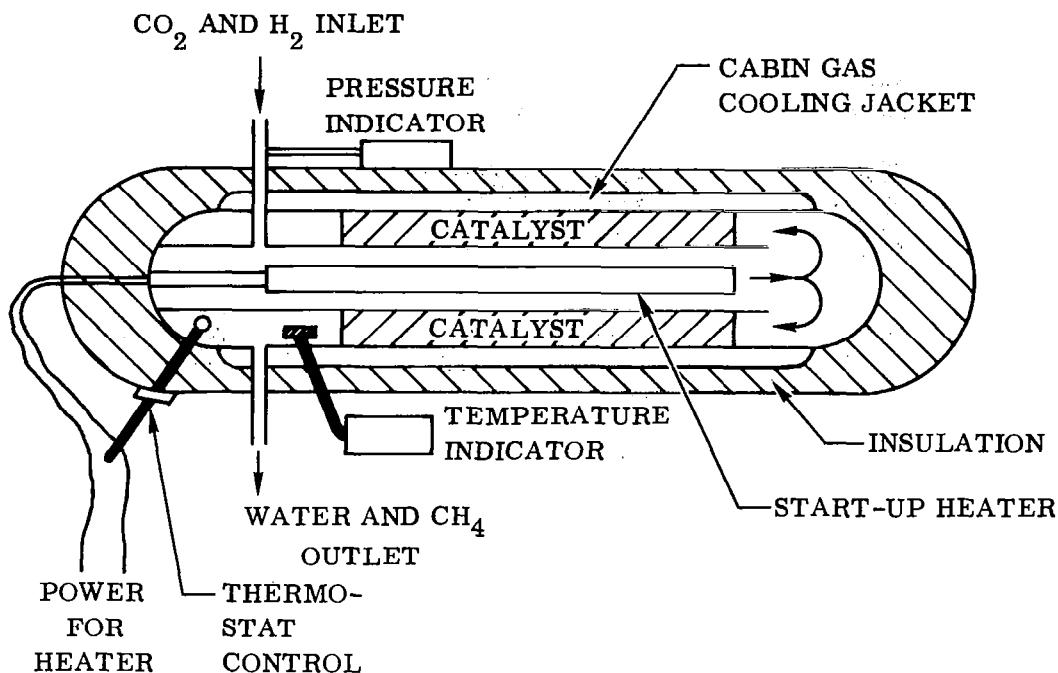


Figure 3.2-8. MRD Sabatier Reactor

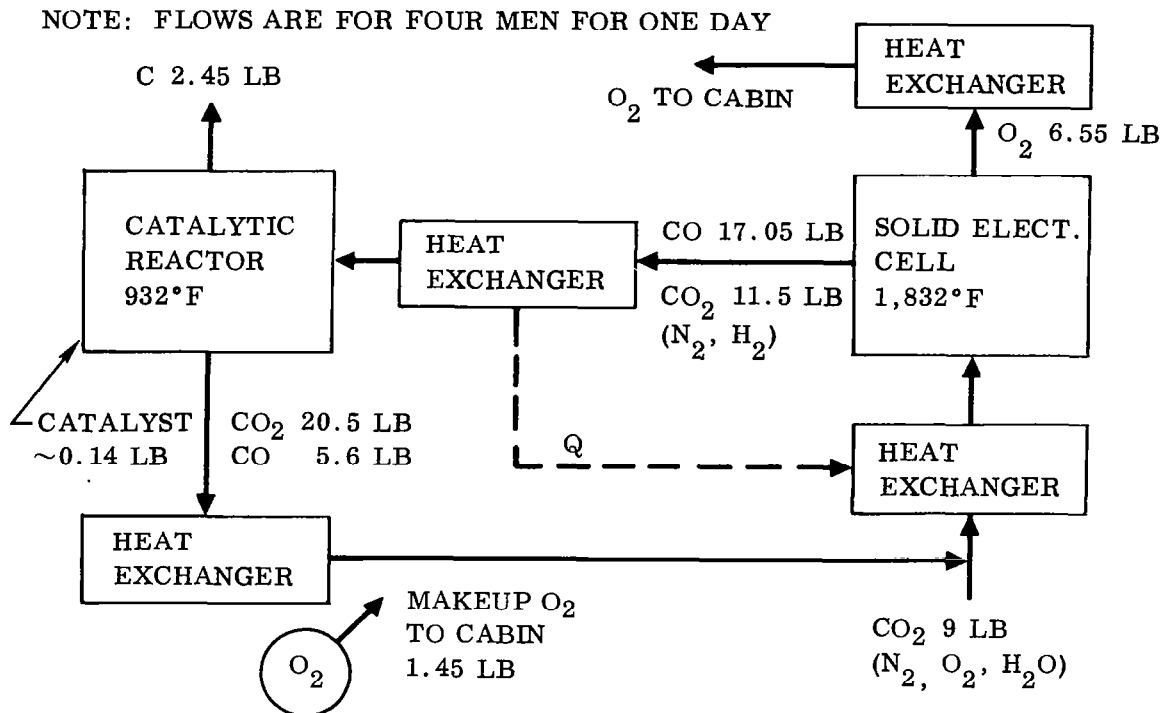


Figure 3.2-9. Solid Electrolyte System

directly from storage, as shown, or from water electrolysis. The latter would probably be preferable because of some net water production in the water system due to metabolic water and water stored in hydrated food. The solid electrolyte cell can purportedly be used to electrolyze this water as well as CO₂. This mode of operation, however, would introduce H₂ into the system.

Isomet reported that the solid electrolyte system is still in an early development stage. Hence it recommended that the system not be considered for use.

Molten Electrolyte System. Molten electrolyte systems are still in the early development stages and would not be available for the subject LSS. The system is based on the electrolysis of lithium carbonate as given by



The lithium oxide is reacted with CO₂ to re-form the carbonate and thus close the cycle. The major problem with the system is the removal of the hard carbon from the cathode, which is normally immersed in the hot (1000° F) molten electrolyte.

Ideally, no H₂ or CO are formed, but actually these gases may be formed if water vapor enters the cell or if the combination of CO₂ feed and power is not accurately controlled. Hence, these gases must be allowed for in the oxygen stream emanating from the cell.

One concept for performing zero-g electrolysis is a rotating cell in which CO₂ is introduced into the electrolyte through a rotating seal. Lithium carbonate is formed and flows to an electrode area, where Li₂CO₃ is electrolyzed and lithium oxide and oxygen flow to the periphery of the cell. Here, due to the centrifugal force, oxygen could be separated and removed through a rotating seal.

General Evaluation. It was apparent that the molten electrolyte and solid electrolyte systems would not be available in time to meet the contract schedules, and methane decomposition could probably not be made available. Hence, the two systems that were considered competitive were the Sabatier system without methane decomposition and the Bosch system.

Effects of Nitrogen in the Concentrated CO₂. As indicated in the system descriptions, contaminants in the concentrated CO₂ represent system inefficiencies and possibly gas losses.

The bleed gas flow rates that must be maintained to compensate for nitrogen contamination are shown in Figures 3.2-10 and 3.2-11. The results are based on a reactor recycle gas composition (excluding N₂) of 50 percent H₂, 20 percent CO, 15 percent CH₄, and 15 percent CO₂. Makeup for these losses would be less than

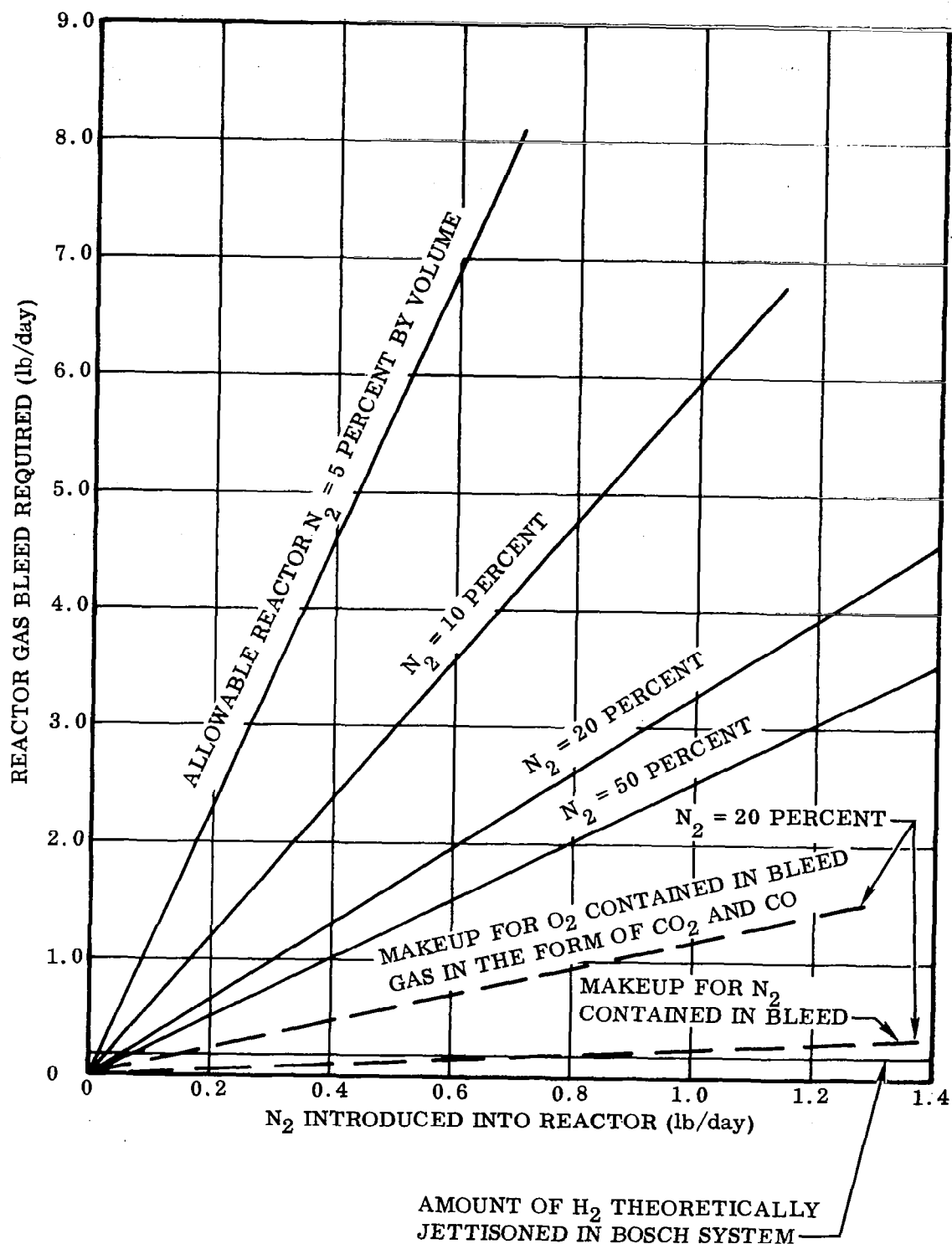


Figure 3.2-10. Recycle Gas Bleed from Bosch System Required to Remove Weight of Nitrogen Introduced

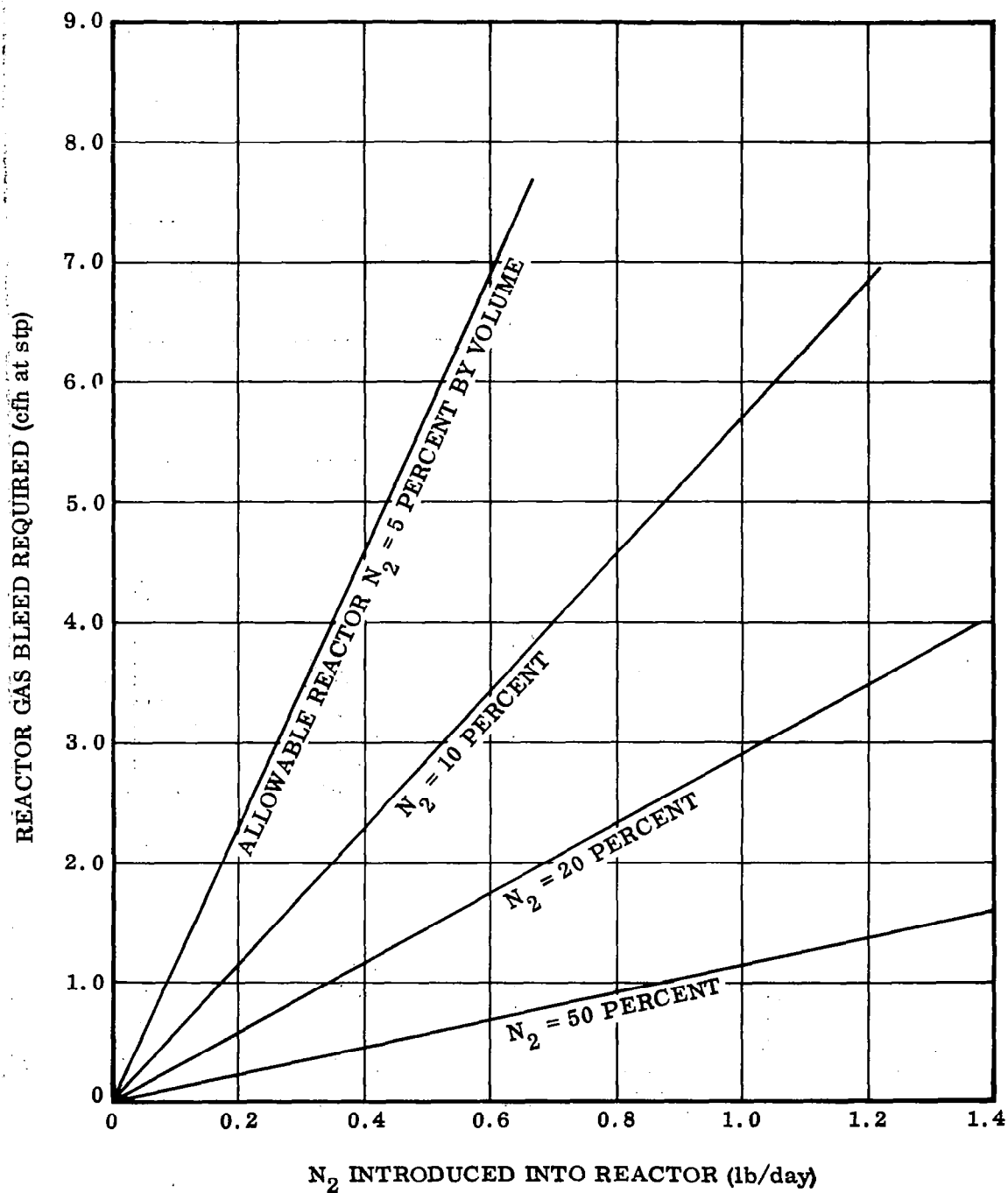


Figure 3.2-11. Recycle Gas Bleed from Bosch System Required to Remove Volume of Nitrogen Introduced

indicated by the solid lines, since only the oxygen and a portion of the hydrogen bled would have to be replenished. As an example, consider 0.5 lb/day of N₂ introduced into a reactor that could accommodate a 20-percent N₂ concentration level. The oxygen in the bleed stream (in the form of CO and CO₂) would be 0.57 lb/day, and H₂ (in the form of H₂ and CH₄) would be 0.12 lb/day, as shown in Figure 3.2-11. Since 0.18 lb/day of H₂ is vented anyway, the makeup gases would be 0.57 lb/day of O₂ plus 0.5 lb/day of N₂. This is considerably less than the total gas bleed of 1.63 lb/day.

An alternative to venting the bleed gases is to pass them through a toxin burner and then into the cabin. The resulting H₂, CH₄, and CO flows contained in the bleed stream are 0.6, 0.175, and 0.23 cfh at standard conditions. If these are mixed with a cabin air flow to the toxin burner at 100 cfh, the above numbers are also approximately the percentage concentrations in the air stream, assuming complete mixing. When compared with the following flammability limits in air, the explosive hazard appears to be negligible.

H ₂	4-74.2 percent
CH ₄	5-15 percent
CO	12.5-74.2 percent

Venting the recycle gases through the catalytic burner and to the cabin constitutes an oxygen regeneration inefficiency, due to the CO₂ and H₂O products that would have to be processed. This inefficiency is represented in Figure 3.2-12 by the amount of oxygen required to burn the necessary bleed gases for various N₂ introduction rates.

A recent study of the CO₂ concentration systems indicates that minimizing N₂ contamination of the CO₂ is not as difficult a problem as first thought. An analysis at Convair on the purging of residual air from molecular sieves also indicates that very low air contamination values can be achieved. A value at 0.1 lb/day of N₂ introduction into the CO₂ reduction system is compatible with the CO₂ concentration, and this value was used in the weight tradeoff studies described in the next section.

3.2.2.2 Technique Selected

Weight Tradeoff Studies. Weight tradeoffs were made on the Sabatier and Bosch systems using the following weight penalties.

$$\begin{array}{ll} \frac{W_T}{W_U O_2} = 1.5 & \frac{W_T}{Q_s} = 0.01 \text{ lb/Btu/hr} \\ \frac{W_T}{W_U H_2O} = 1.05 & \frac{W_T}{W_U N_2} = 1.5 \end{array}$$

$$\frac{W_T}{W_{U H_2}} = 2.5 \quad \frac{W_T}{KW} = 290 \text{ lb/kw}$$

where

$$\begin{aligned} W_T &= \text{total weight penalty for storage, power, or heat rejection} \\ W_U &= \text{available gas} \\ Q_s &= \text{sensible heat} \end{aligned}$$

The H_2 storage penalty is approximately correct for either subcritical or supercritical storage. For high-pressure storage, it is about 15; for storage in the form of NH_3 , it is about 6; and for H_2O storage it is greater than 8. The volume required for subcritical storage of H_2 for 90 days is about 15 ft^3 .

The net water inventory increase in the water recycling system was taken as 1.3 lb/day, estimated for water recoverable from metabolic water and water contained in hydrated foods. Fecal water is not reclaimed.

Oxygen Storage. The Bosch and Sabatier systems both pose the question of whether to store oxygen or to store water and electrolyze it to produce makeup oxygen not available in the water obtained from the water purification system. Using preliminary values for the electrolysis penalties, the comparisons are presented in Figure 3.2-13. The penalties used were 5.35 pounds and 123 watts/lb of O_2 required per day. The time at which the crossover occurs is independent of the O_2 use rate. The curves show very little advantage in electrolyzing water over a one-year duration.

Bosch System Weights. The Tapco system weight breakdown includes about 40 pounds for the catalyst assembly and 24 pounds for electrolysis. The catalyst assembly includes both consumable catalyst and supporting structure. Catalyst available for consumption, estimated at 30 pounds, was subtracted from the fixed hardware weight. The 24-pound electrolysis unit was judged to be optimistic, and a more realistic penalty of 43 pounds plus 985 watts was substituted. In addition, various components, such as the carbon blowdown assembly, ducting, and valves, appear to be unaccounted for. Hence, an additional 10 pounds plus 100 watts was added to the system. The resulting fixed weight plus power for the Tapco system was 99 pounds plus 1390 watts (403 pounds at 290 lb/kw).

The heat rejection penalty was also calculated. For the 985 watts for electrolysis, about 12 pounds is required to reject the resulting heat. Essentially all the remaining power of 405 watts appears as sensible heat and carries a penalty of 13.8 pounds. In addition, the heat of reaction of 921 Btu/lb of CO_2 reacted results in 346 Btu/hr and carries a weight penalty of 3.5 pounds. The total heat rejection weight penalty is, therefore, 29.3 pounds. These values are summarized in Table 3.2-VIII.

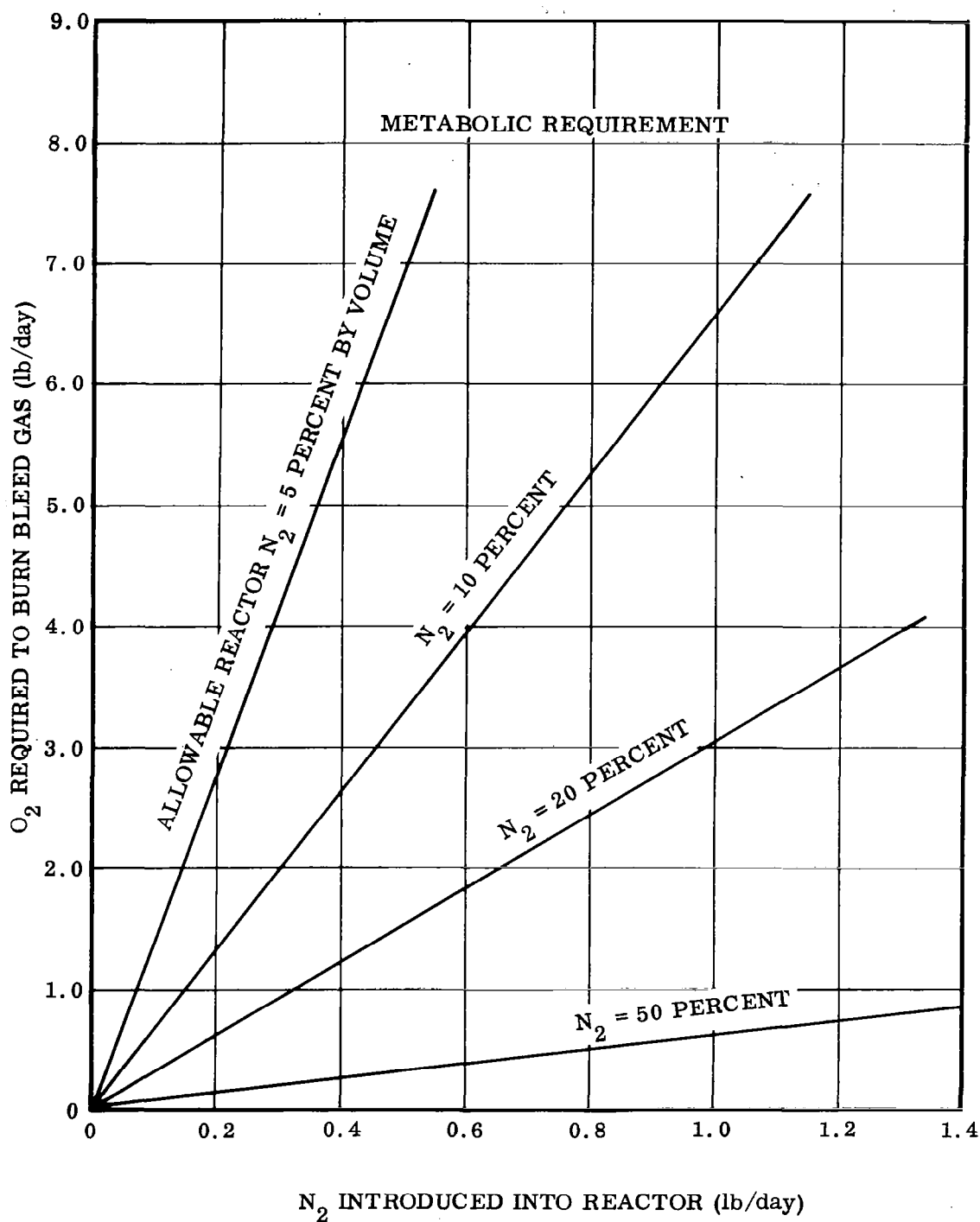


Figure 3.2-12. Oxygen Required to Burn Bosch Reactor Gases

- BASED ON:
1. H_2O STORAGE PENALTY $\left(\frac{W_T}{W_U}\right)$ OF 1.05
 2. POWER PENALTY OF 290 LB/KW
 3. ELECTROLYSIS HARDWARE = 5.35 LB/LB O_2 /DAY
 4. ELECT. POWER = 123 WATTS/LB O_2

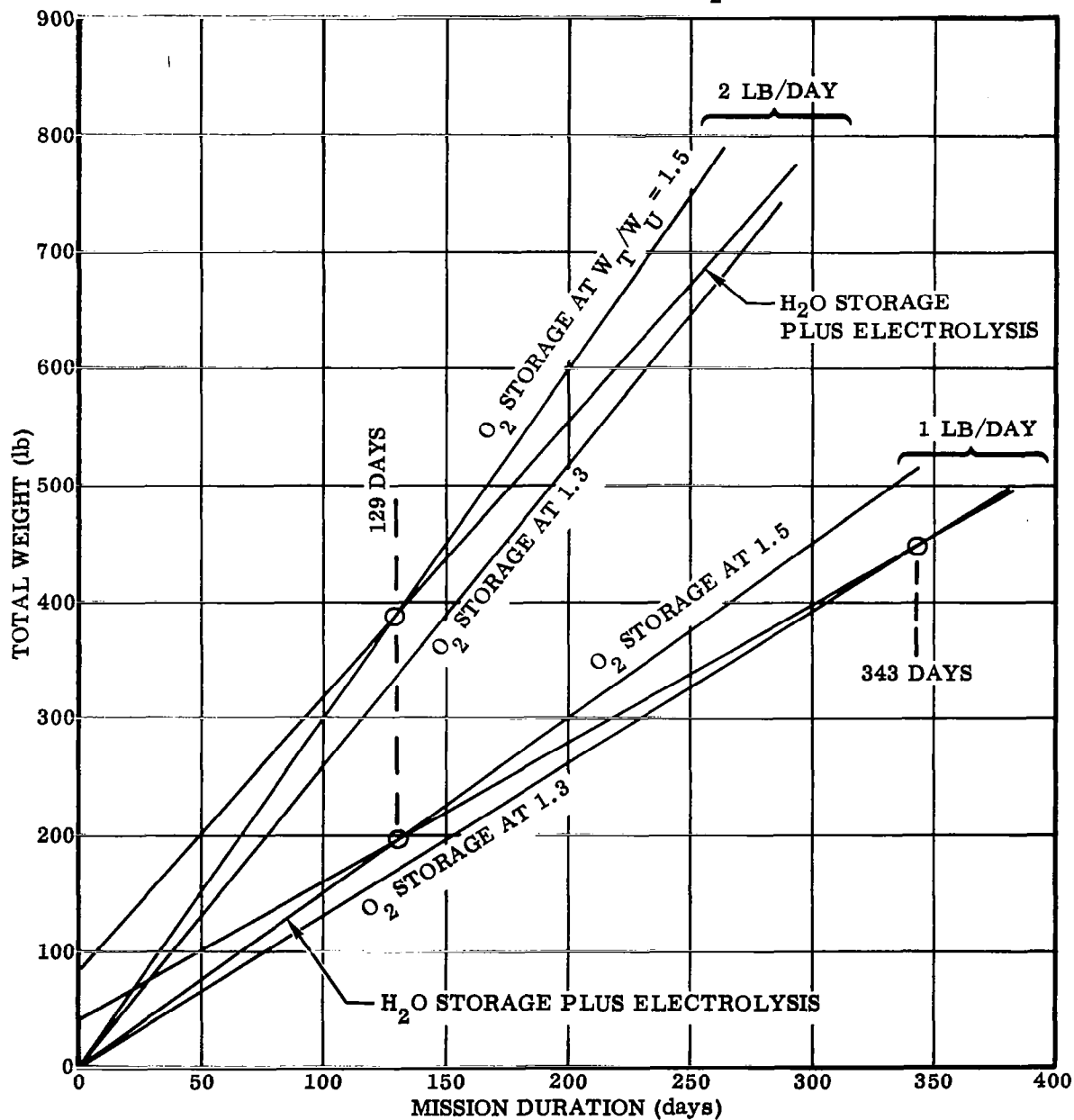


Figure 3.2-13. Weight Comparison Between Storing Oxygen and Storing Water for Electrolysis

Table 3.2-VIII. Bosch and Sabatier CO₂ Reduction System Adjusted Weights

SYSTEM	FIXED HARDWARE (lb)	WEIGHT PENALTY FOR POWER (lb)	WEIGHT PENALTY FOR HEAT REJECTION (lb)	TOTAL FIXED WEIGHT PENALTY (lb)	EXPENDABLE WEIGHT (lb/day)
Pure CO ₂					
Tapco Bosch	99*	403	29	531	0.75
MRD Bosch	164*	432	33	629	0.75
MRD Sabatier System with H ₂ storage @ $\frac{W_T}{W_U} = 2.5$	97	290	19	406	2.34
MRD Sabatier System without H ₂ Storage	97	290	19	406	4.05
Additional penalty for 0.1 lb/day of N ₂ contaminating CO ₂					
Bosch Systems				5	0.29
Sabatier Systems					0.15
*Includes electrolysis weight of 43 pounds, but not catalyst weight.					

The MRD system weighs 129 pounds and requires 505 watts without an electrolysis unit. The 8 pounds of catalyst can be subtracted from the fixed hardware. Adding the standard electrolysis penalty of 43 pounds plus 985 watts, the total penalty is 164 pounds plus 1490 watts.

Again, the electrolysis heat rejection penalty is 12 pounds, and the heat of reaction penalty is 3.5 pounds. Power, excluding electrolysis, is 505 watts and carries a heat rejection penalty of 17.2 pounds. Hence the total penalty is 32.7 pounds for cooling.

The expendable weights required for the Bosch systems are about 0.14 lb/day for catalyst, 0.25 lb/day conservatively estimated for carbon filtration storage and miscellaneous, and 1.64 lb/day of makeup water; for this makeup water, 1.3 pounds was assumed to be supplied from the water reclamation system and the remainder from storage. Thus the water plus storage penalty becomes 0.36 lb/day.

In addition to the above expendables, an impure CO₂ stream can introduce further penalties. For the Bosch system, the worst penalty over a one-year duration results from jettisoning the bleed recycle gases; this was assumed in one set of tradeoff curves. The allowable Bosch reactor N₂ concentration was assumed to be 20 percent, and the N₂ introduction was assumed to be 0.1 lb/day. For this case, the O₂ jettisoned is 0.116 lb/day, and the H₂ jettisoned is 0.024 lb/day, which need not be made up. Using electrolysis for the O₂ makeup, the penalty is

$$0.116 [5.35 + (0.123) (290)] \text{ pounds} + (0.116) (1.05) (9/8) \text{ lb/day} \\ = 4.76 \text{ pounds plus } 0.137 \text{ lb/day}$$

The makeup plus tankage penalty for N₂ is 0.15 lb/day. Hence the total additional penalty is 4.76 pounds plus 0.287 lb/day, which is shown in Table 3.2-VIII.

Sabatier System Weights. The Sabatier system fixed hardware weights were estimated by MRD and were adjusted by adding the standard electrolysis penalty of 43 pounds plus 985 watts. The result is 97 pounds plus 1000 watts. The power weight penalty is 290 pounds.

Heat rejection for electrolysis is again 12 pounds. The heat of reaction is 1640 Btu/lb of CO₂ or 615 Btu/hr, for a weight penalty of 6.15 pounds. The 15 watts required, exclusive of electrolysis power, results in a heat rejection penalty of 0.51 pound, and the total heat rejection penalty is 18.7 pounds. The expendable weights required are 1.6 lb/day for H₂ makeup and storage and 2.0 lb/day for water. Of the water required, 1.3 lb/day will come from the water system; the remainder must be stored at a water-plus-tankage penalty of 0.74 lb/day.

The storage of H₂ is viewed very unfavorably, not only because of weight but also because of reliability and safety considerations. An alternative to storing hydrogen would be to accept some direct CO₂ loss by reacting only the amount of

H₂ from the electrolysis of water necessary to produce metabolic oxygen. The amount of H₂ thus available would be 1 lb/day; using a 95-percent conversion of this H₂ to water in the Sabatier system would give 4.28 pounds of H₂O. Hence the makeup water would be 9.0-4.28-1.3 = 3.66 lb/day. Including 5 percent for tankage, this becomes 3.85 lb/day, compared with the other penalty of 2.34 lb/day. The system is tabulated without H₂ storage.

Using an H₂ storage penalty $\left(\frac{W_T}{W_U H_2}\right)$ of 4.8 rather than 2.5 would result in an expendable equal to that of the system not storing H₂. It may therefore be concluded that if the H₂ storage penalty approached 4.8 it would be more desirable to eliminate H₂ storage altogether and accept the resulting CO₂ loss.

Nitrogen introduced into the Sabatier systems with the CO₂ merely causes an equal N₂ loss. For an introduction of 0.1 lb/day, the resulting makeup N₂ plus storage would be 0.15 lb/day.

Weight Comparison of Bosch and Sabatier Systems. Weight comparisons of the systems are shown in Figure 3.2-14 along with the major assumptions used in obtaining the curves. The Bosch systems are lighter by far for the one-year missions, and both the Sabatier and Bosch systems are considerably lighter than stored oxygen, which is shown for reference. The upper Sabatier system curve corresponds to no H₂ storage; thus only about half of the CO₂ is reacted with the available H₂ from electrolysis. The remaining CO₂ is jettisoned, and the resulting oxygen loss is made up from electrolysis of stored H₂O.

Figure 3.2-15 shows that introducing 0.1 lb/day of N₂ to the Sabatier and Bosch reactors, assuming that the resulting Bosch reactor bleed gas is jettisoned, extends the crossover point about 15 days. If the Bosch bleed gases could be oxidized in a catalytic burner, the weight penalty would be less than that of jettisoning for a one-year mission.

Maintainability. The Sabatier system appears to be the least complex and to require less maintenance than the other systems studied. The most serious problem with this system appears to be the storage and handling requirements for makeup H₂. Catalyst poisoning and replacement, if it occurred, would also present maintenance problems.

The Bosch system appears to present more maintenance problems than the Sabatier because more elements are subject to high temperature and because of the potential buildup of carbon deposits on parts that are difficult to disassemble and clean.

Comparative Reliability of Bosch and Sabatier System. Reliability estimates were made for three configurations: Bosch, Sabatier, and a unit that could operate in either mode, (B + S₁).

BASED ON:

1. O_2 REQ. = 8.0 LB/DAY
2. CO_2 = 9.0 LB/DAY
3. BOSCH CARBON-TO-CATALYST CONSUMPTION ≈ 20
4. SABATIER OVERALL CONVERSION EFFICIENCY = 95 PERCENT
5. PURE CO_2 FED TO REACTORS
6. NO CO_2 CONCENTRATION PENALTY INCLUDED

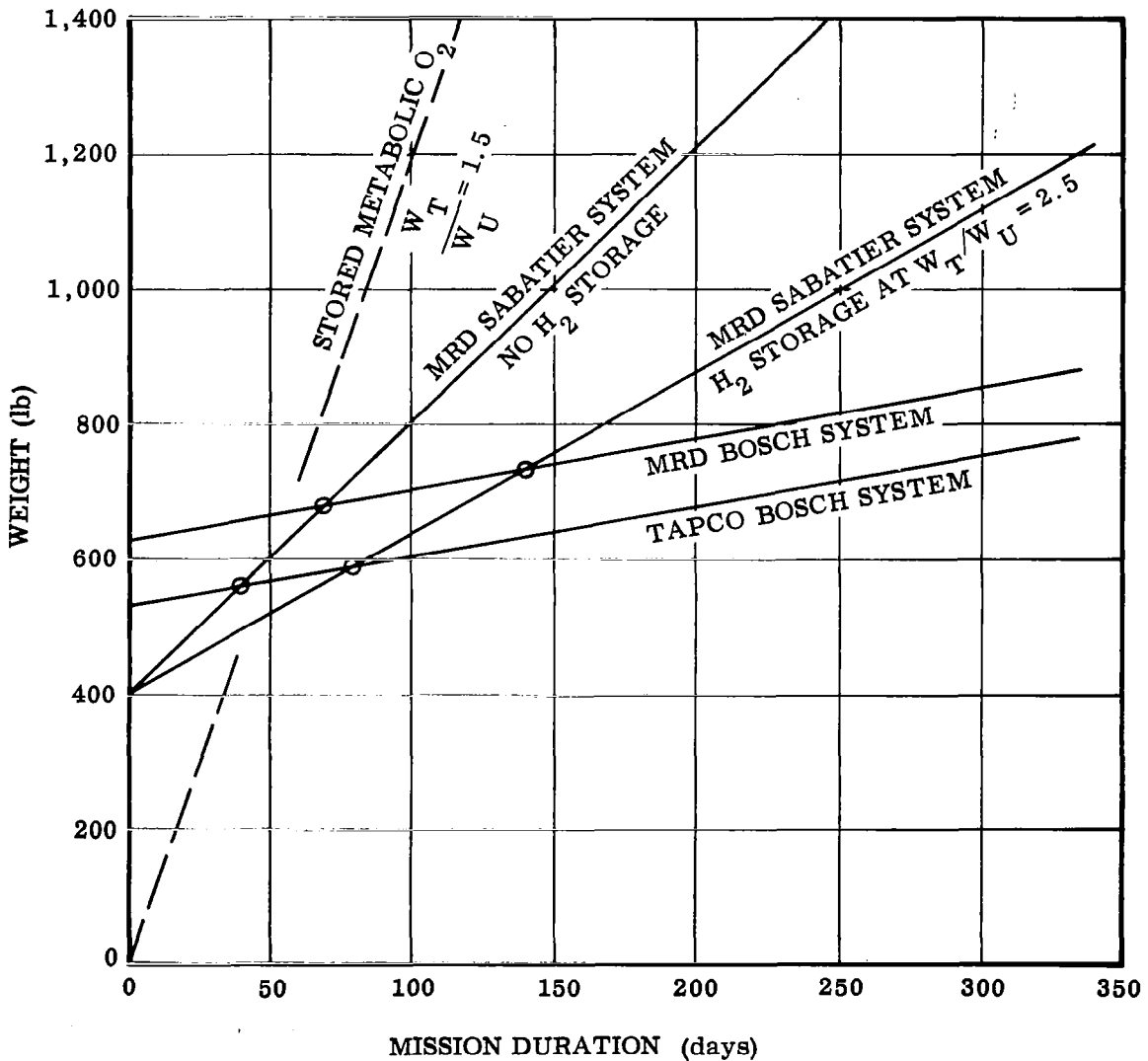


Figure 3.2-14. Bosch and Sabatier Weight Penalty Comparisons

BASED ON:

1. FOUR-MAN LEVEL
2. N_2 REMOVAL FROM BOSCH SYSTEM BY BLEED OVERBOARD
3. N_2 CONCENTRATION IN BOSCH REACTOR = 20 PERCENT

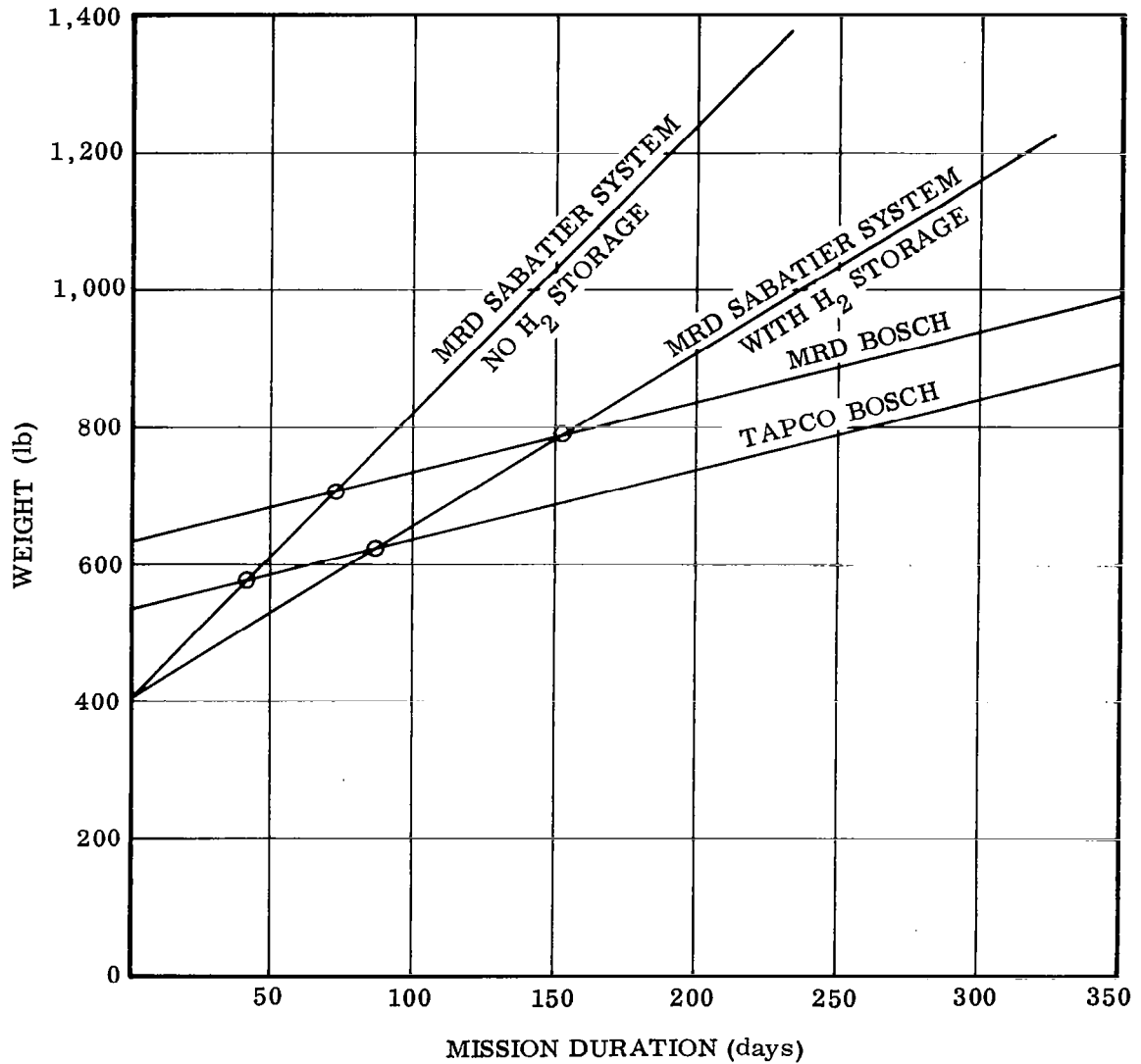


Figure 3.2-15. Bosch and Sabatier System Weight Penalty Comparisons with 0.1 lb/day N_2 Contamination

The ratio of the failure probabilities for each configuration is presented in Figure 3.2-16 as a function of development time.

Plot 1 shows the ratio of the Bosch system, $P_f(B)$, to that of the Sabatier system with H_2 storage, $P_f(S_2)$.

Plot 2 shows the ratio of a Bosch system in either the Bosch or Sabatier $P_f(B + S_1)$ mode to that of the Sabatier system with H_2 storage.

Plots 2 and 3 show the difference in risk due to H_2 storage, where S_1 denotes a Sabatier system without H_2 storage.

Conclusions and Recommendations. The results of the studies on the CO_2 reduction systems are summarized in Table 3.2-IX. The molten electrolyte systems and the solid electrolyte system would not be available in time to meet the program schedules and were eliminated from consideration. The Sabatier systems with methane decomposition were also considered to be unavailable for inclusion in the subject LSS.

The Bosch reaction offered the greatest potential for the minimization of overall system weight on mission durations exceeding about three months and was selected as the optimum physical-chemical CO_2 reduction system.

The Sabatier reaction was selected as a backup system, because it offered substantial weight savings over a stored oxygen system and required the least development of the physical-chemical systems.

3.2.3 WATER ELECTROLYSIS. Nine proposed water electrolysis techniques were evaluated. These techniques received water vapor in the cabin air stream or liquid water from other sources, including the CO_2 reduction apparatus. The outputs were gaseous O_2 returned to the cabin atmosphere and gaseous H_2 recycled into the CO_2 reduction unit.

3.2.3.1 Fundamental Behavior. The basic component of all electrolysis units is the individual cell. In general, the cells are stacked so as to be electrically in series, with their liquid and gas flows manifolded in parallel. According to Faraday's Law, to generate the desired daily output of 7.48 pounds of O_2 requires a continuous total current of 475 amperes. If there are n cells, the current will be $475/n$ amperes per cell. The current per unit area of the cell conduction path is called "current density." The "ideal" voltage is the reversible potential, which is 1.23 volts if the water, hydrogen, and oxygen are all at $77^\circ F$. Actual cells require an excess voltage, and the power corresponding to this overvoltage approximates the heat that must be rejected.

In selecting a technique requiring minimum power, the proper selection of cathode and anode materials is important. In general, lower overvoltages are obtained when the electrode material is finely divided so as to expose a large surface. For example,

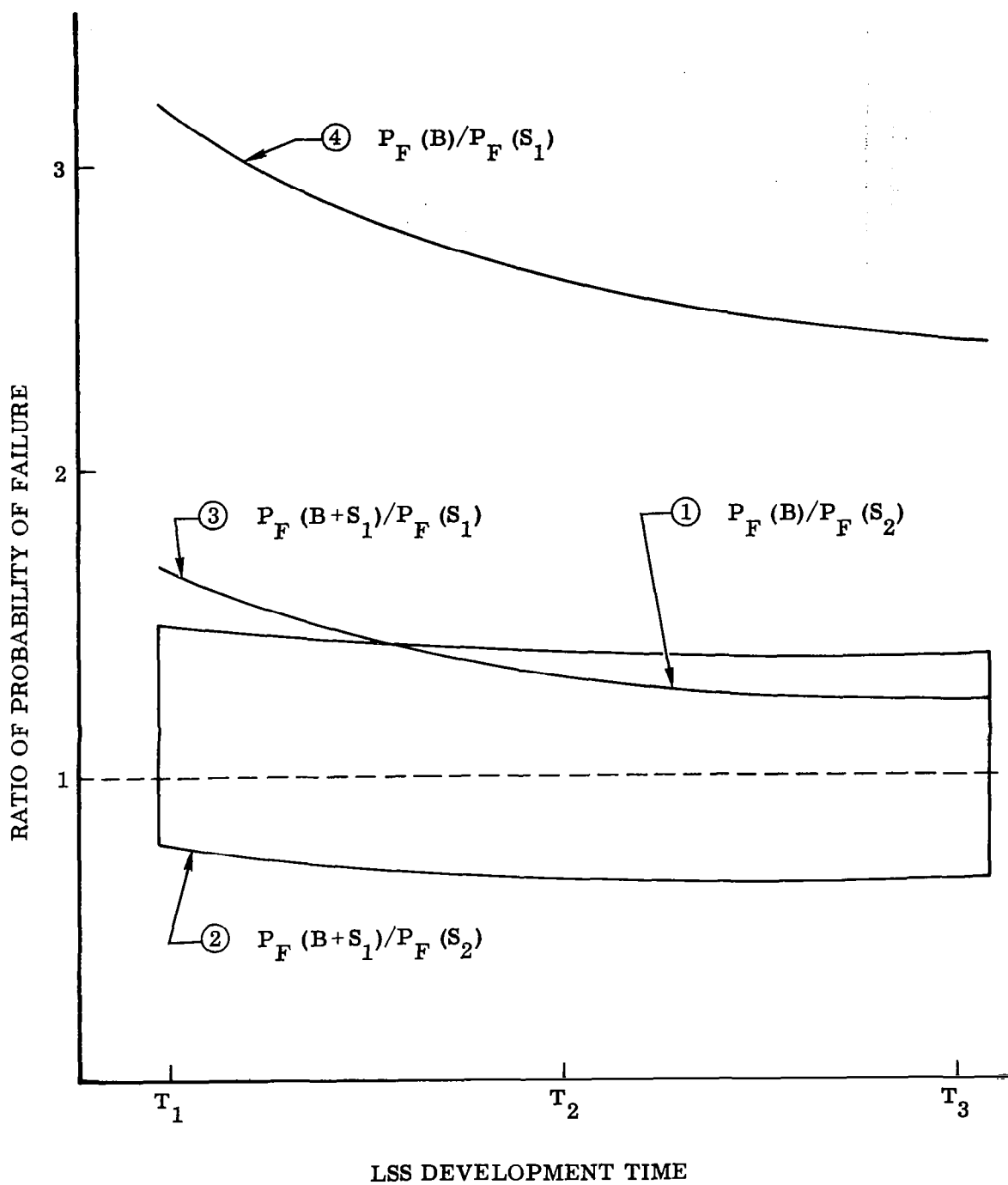


Figure 3.2-16. Reliability Comparisons for Various Configurations of the Bosch and Sabatier Systems

Table 3.2-IX. Rating Chart, CO₂ Reduction Unit

	SABATIER	BOSCH	SOLID ELECTROLYTE	MOLTEN ELECTROLYTE
Reliability	1*	2*	---	---
Maintainability	1	2	---	---
Safety	1	1	---	---
Availability	Yes	Yes	No	No
Total Weight (Hardware, Power, Heat Rejection)	406 lb	531-629 lb	584-1090 lb	650 lb
Volume	2.2 ft ³ **	3.3 ft ³	---	---
Confidence	1	1***	---	---
Expendable Weight	2.37-4.05 lb/day	0.75 lb/day	---	---

* See Figure 3.2-16.

** Does not include storage for H₂.

*** Based on the ability to convert to Sabatier mode as an alternate.

Notes: Ratings are in the order of ranking. Availability is based on vendor estimates.
Confidence is based on Convair appraisal of potential to develop satisfactory system on schedule.

smooth platinum has a higher overvoltage than does very finely divided platinum, known as platinum black. Current density is significant in achieving minimum weight and power. Small cells mean lower hardware weight but higher current density. As a consequence, higher voltage and more power are needed to maintain the required current. Conversely, power is saved by accepting the hardware weight penalty for larger cells.

The heat to be rejected in electrolysis is the difference between actual power to the unit and the "ideal" power of 585 watts. The manner of heat rejection varies with cell design. In some cases a separate cooling fluid is circulated through tubes within the cells. Another method is to use the electrolyte as a heat transport fluid by circulating it through a heat exchanger external to the cell. The cell temperature is limited by characteristics of cell materials and by vapor pressure of the electrolyte.

The principal problem in zero-g electrolysis is separation of the gaseous products from the liquid electrolyte. If electrolyte is forced away from the electrodes by gas as it evolves, current is interrupted and electrolysis ceases. On the other hand, flooding of electrolyte into the product gases would require handling and separation of the corrosive liquid. Many zero-g techniques are based either on differences in inertia of liquid and gas (as in centrifuges and vortex streams) or on capillarity or surface tension effects, which produce semipermeable membranes or phase-separation boundaries. The use of ion-exchange membranes as both current conductors and liquid-gas barriers is somewhat different than that of other microporous surfaces, since the usual van der Waals forces responsible for most surface tension effects are augmented by ion-dipole forces. Other physical principles, such as the use of magnetic or electric force fields to replace gravity were studied, but the fields required are too large to be applicable.

All data on the techniques considered were based on information from vendors. Most weight and power data were presented on a basis of O₂ production at a rate of 2.0 lb/man-day, or 8.0 lb/day for the four-man crew. All were adjusted to a common basis of 1.87 lb/man-day or 7.48 lb/day for the four-man crew, using linear scaling.

The heat rejection load was calculated from the difference between actual electrolysis power and the ideal continuous power of 585 watts. The total load was assumed to be sensible heat except when H₂ and O₂ products were carried in a liquid H₂O stream. For this case, the gases were assumed to be saturated with water vapor and the corresponding latent heat was calculated. Weight penalties were charged at 0.01 lb/Btu per hour for sensible heat and 28 lb/lb H₂O per hour for latent heat.

3.2.3.2 Techniques Considered. The techniques considered for electrolysis were as follows.

- a. Ion-exchange membranes with resin cation packing.
- b. Double ion-exchange membranes with H₂SO₄ electrolyte.

- c. Wick-type cell using KOH electrolyte.
- d. Hydrated P_2O_5 matrix cell.
- e. Rotating cell using NaOH electrolyte.
- f. Palladium cathode cell.
- g. Porous metallic electrode cell with KOH electrolyte.

Two variations of the P_2O_5 cell -- the membrane resin cell, and the porous metallic electrode cell -- were evaluated.

In the membrane cell with resin packing, water is fed into an anode chamber containing cation resin sandwiched between a metal anode and a cation membrane. (See Figure 3.2-17.) Oxygen is formed on the anode, and hydrogen ions are transmitted through the cation resin and membrane into a cathode compartment. Water and O_2 emanate from the anode compartment, and water and H_2 emanate from the cathode compartment. Gas-liquid separators are required for these streams. At the time of the evaluations, the power requirement of this technique was comparatively high, due to the resistance of the cation packings.

In the double membrane cell, (Figure 3.2-18) water is fed into a narrow space containing H_2SO_4 electrolyte between two ion-exchange membranes. Each membrane assembly has a thin catalyst/electrode bonded to the outer face, where the gaseous products are evolved. The electrode is a platinum screen with a platinum black coating. The membranes are current conductors and provide the liquid-gas barrier.

The wick-type electrolysis unit (Figure 3.2-19) relies on capillary forces to feed electrolyte to the cells. The 30-percent KOH electrolyte is contained in a common reservoir and is fed into the cells by nylon wicks. In each cell, the wick is in direct contact with the hydrogen electrode on one side. The other side of the wick is pressed against a layer of asbestos paper that holds electrolyte against the oxygen electrode. Both electrodes are of platinum black on a platinum screen and are pressed against 16-mesh Monel screens that serve as current collectors and provide gas passages. One problem is that of maintaining positive gas-liquid interfaces by surface tension alone, without electrolyte bubbling and spray. The interface is quite sensitive to pressure fluctuations. Also, a parallel electrical path exists between end cells through the reservoir, and shorting could occur. The technique does not include any provision for cell cooling.

In the hydrated P_2O_5 technique (Figure 3.2-20), moist cabin air flows into a cell, where the water vapor is absorbed into a matrix of P_2O_5 with a binder to form an acid. Electrolysis of the acid releases O_2 and H_2 gases and re-forms the P_2O_5 . The matrix separates the two gases. Since this method dehumidifies cabin air, that function might be eliminated from the main cabin air heat exchanger and water separator.

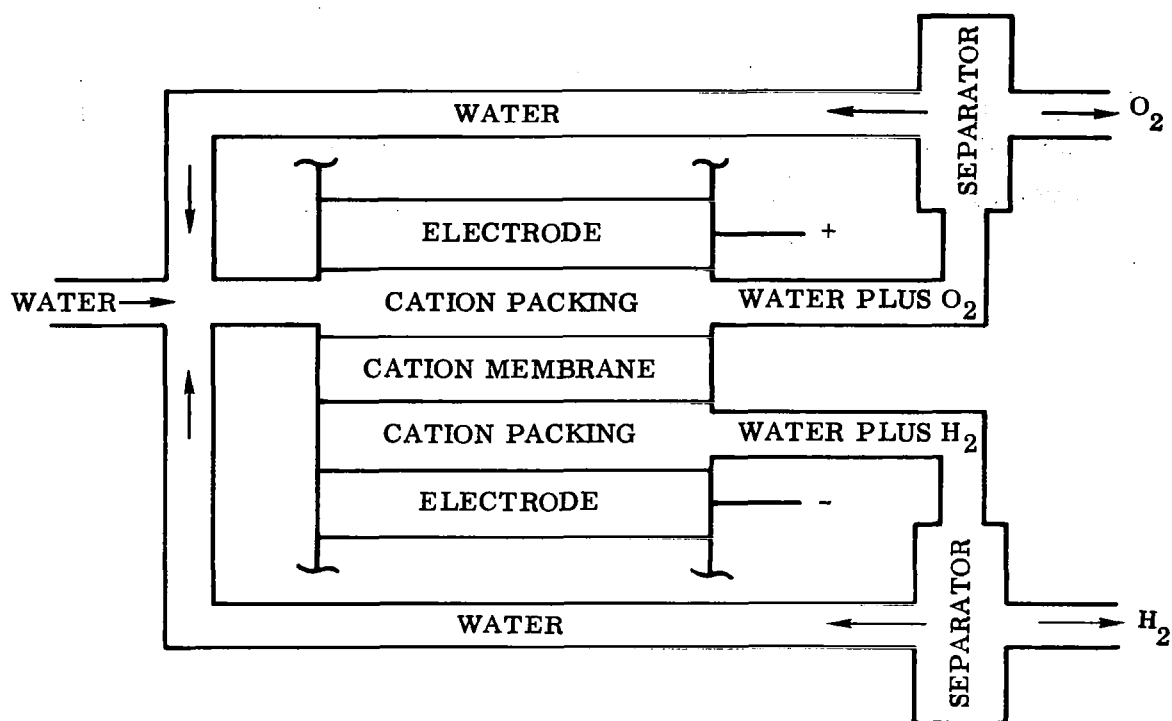


Figure 3.2-17. Membrane Resin Cell

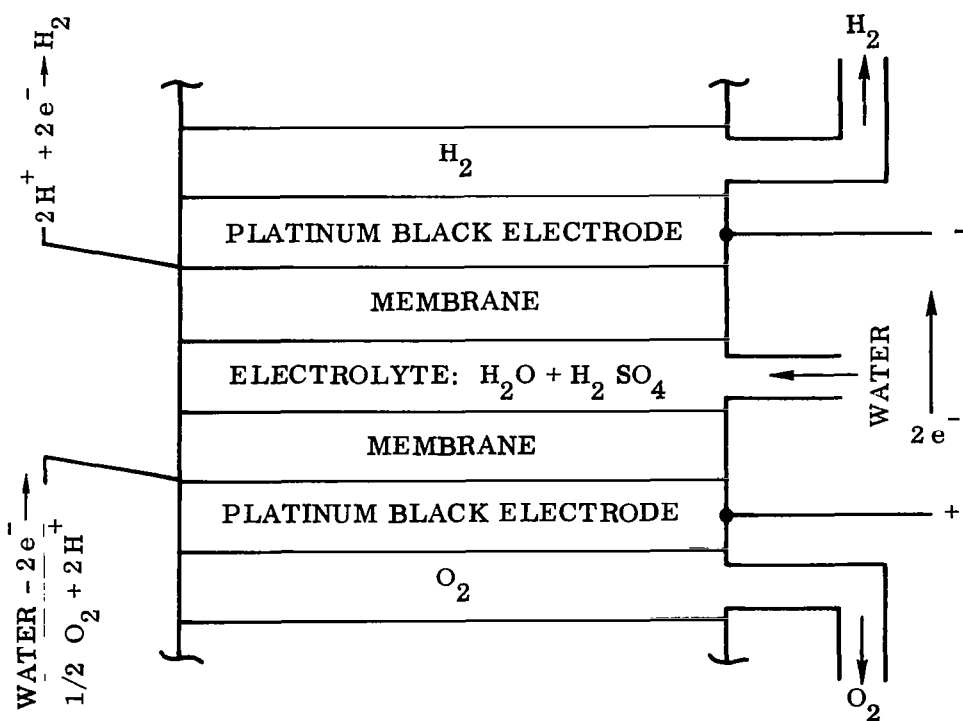


Figure 3.2-18. Double Membrane Cell

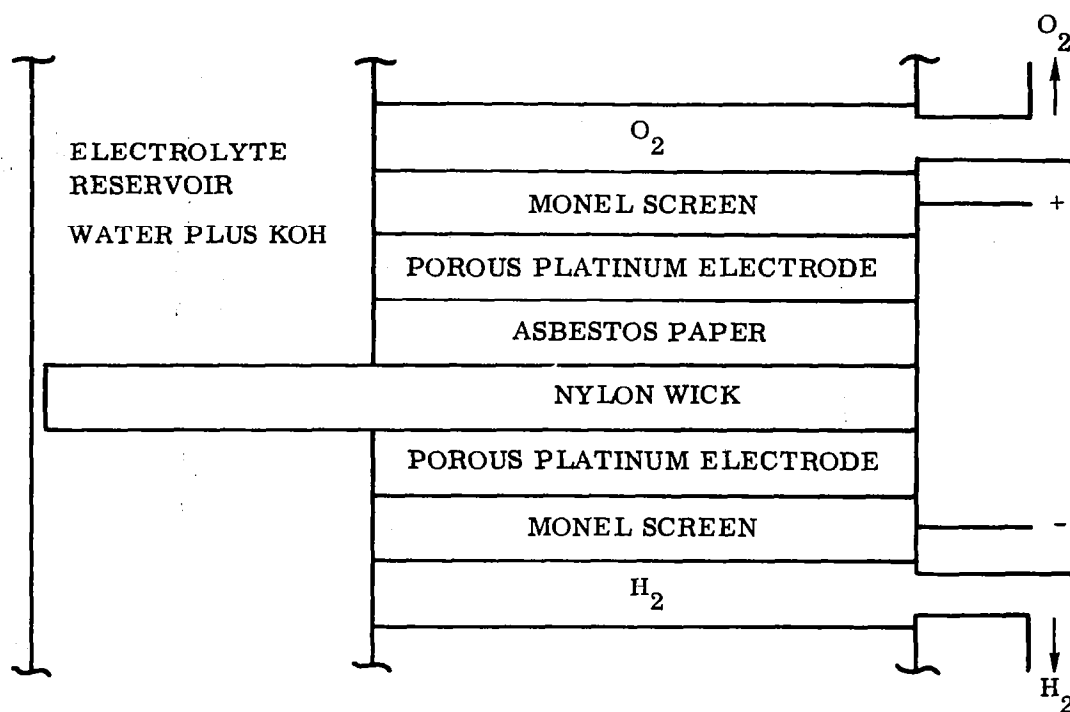


Figure 3.2-19. Wick-type Unit

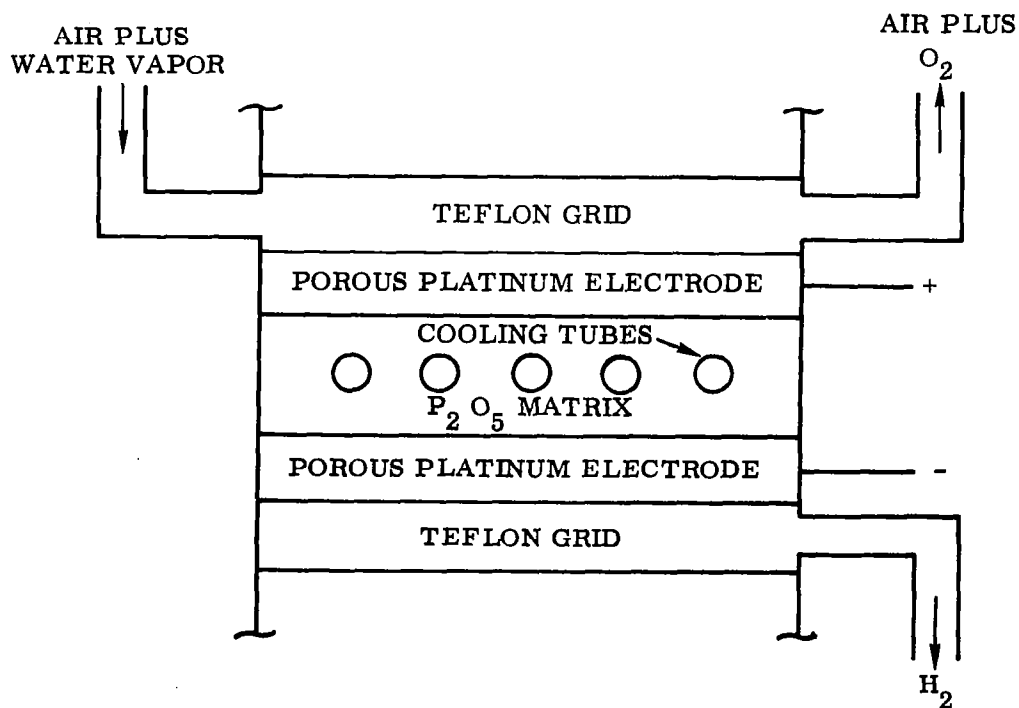


Figure 3.2-20. Phosphorous Pentoxide Cell

However, the weight saved is relatively small. Even when mostly in the form of phosphoric acid, P_2O_5 is an inherently poor conductor of electricity. Therefore the technique requires relatively high power. If the membrane is made very thin to overcome the low electrical conductivity, difficulty will be experienced in preventing the diffusion of hydrogen into the oxygen.

A rotating electrolysis unit uses industrial water electrolysis principles in a unit that rotates so as to substitute a centrifugal force field for the gravity force field. (See Figure 3.2-21.) Rotation solves the gas-liquid separation problem, but other problems arise, such as with fluid seals and slip rings.

A cell in which cathodically discharged hydrogen from water vapor would diffuse through palladium-silver alloy foil was proposed. However, this cell was early in the development stage, and a complete description of the concept was not available. Since, in addition, it did not in itself provide a solution to the zero-gravity separation of oxygen from the electrolyte in the cell, it was not a suitable choice for the NASA system.

A cell using double porous metal electrodes and KOH electrolyte was considered. (See Figure 3.2-22.) The product H_2 and O_2 were carried from the cell by electrolyte flow, and cyclone-type liquid-gas separators were used. The weight of this system was comparatively high.

3.2.3.3 Technique Selected. The cell design using double ion-exchange membranes with H_2SO_4 electrolyte was selected for use in the program. The basic membrane assembly incorporated in the cell is similar to that used in the GE fuel cell, on which successful testing has been demonstrated. The membranes appear to offer the most positive gas-liquid barrier, and a gas pressure is maintained to further minimize the possibility of H_2SO_4 carryover into the H_2 or O_2 streams. The cell cooling design is superior and provides for liquid coolant tubes within the individual cells. Since electrolyte circulation is not required, potential leakage and corrosion problems are reduced. The cell design results in a comparatively low power requirement.

A possible disadvantage of the technique is membrane degradation, but the design was judged adequate to prevent this problem. For example, membrane area is large enough to keep current density and resulting heat generation in the membrane relatively low. The cooling system further protects the membranes from heat damage. In addition, the membranes have exhibited long life under relatively severe use in previous testing.

3.2.4 ATMOSPHERIC CONTAMINANT CONTROL

3.2.4.1 Functional Requirements. The function of the atmospheric contaminant control system is to control all anticipated contaminants except CO_2 and water vapor, which are controlled by other systems.

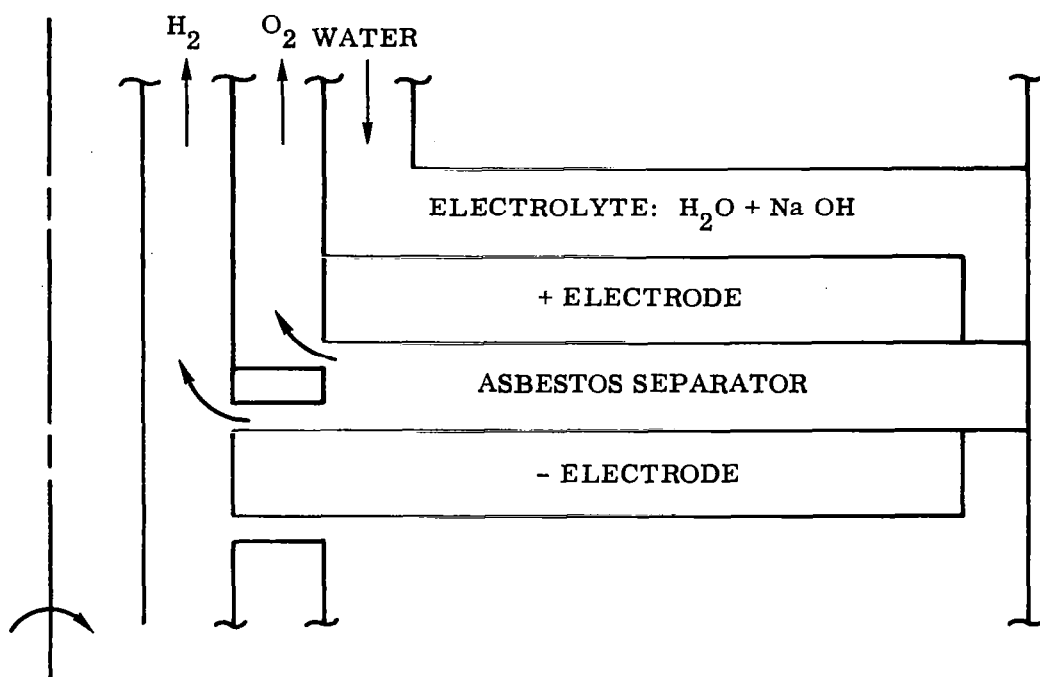


Figure 3.2-21. Rotating Cell

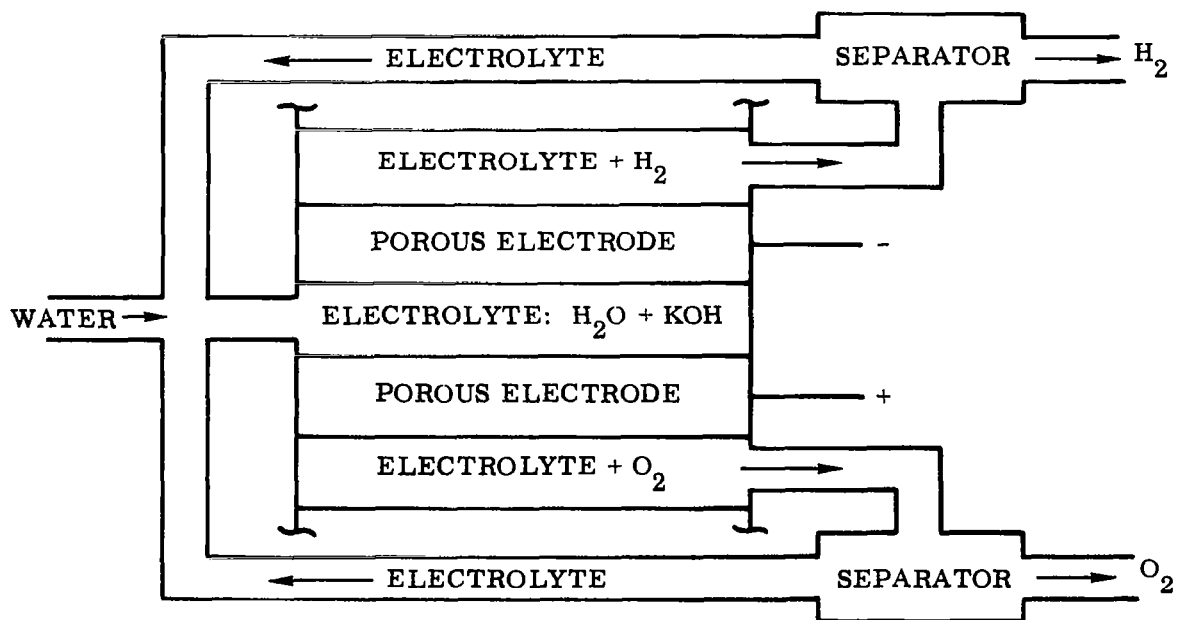


Figure 3.2-22. Potassium Hydroxide Cell

3.2.4.2 Possible Contaminants and Sources. Table 3.2-X presents a brief summary of the possible sources of contamination aboard a spacecraft under flight conditions and the probable contaminants.

A large number of compounds, shown by Tables 3.2-XI and 3.2-XII, have been identified in submarine atmospheres. Some contaminants, such as the Freons and "cigarette smoke," are not expected aboard the spacecraft, since no Freon is being used and no smoking is allowed.

Information on trace atmosphere contaminants has been obtained in the two-man space cabin simulator at the School of Aerospace Medicine, Brooks Air Force Base, Texas. Results are summarized in Table 3.2-XIII. The simulator contaminant control system used in these tests consisted of 50 pounds of activated charcoal with the air recycled once per minute.

A simulator test has been completed at the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, where three men were placed under simulated space conditions for 30 days. The air was circulated through activated charcoal to control atmospheric contaminants and odors. Table 3.2-XIV shows the compounds identified from the desorption of the charcoal.

Contaminant information from the Mercury flights is contained in Table 3.2-XV. Also listed are the approximate concentrations that would have been present in the spacecraft atmosphere had all the recovered contaminant been dispersed in the free volume of the cabin at any one time.

3.2.4.3 Rate of Contaminant Introduction. The rates at which the different possible contaminants are introduced into the spacecraft environment are extremely difficult to estimate. The total quantity of toxic trace materials would be expected to be small under normal conditions, but malfunctions or breakage could rapidly cause dangerous concentrations.

Many contaminants are introduced by astronauts themselves. The rates at which contaminants are introduced by man can be estimated with fair accuracy. (See Table 3.2-XVI.)

3.2.4.4 Acceptable Contaminant Levels. The two commonly employed contaminant concentration level designations are the maximal acceptable concentration (MAC) and the threshold limit value (TLV).

The MAC of the ASA, as defined in 1957 by the Z-37 committee, is a limiting concentration, or ceiling, below which all values should fluctuate; i.e., the MAC values are maximums that may never be exceeded.

Table 3.2-X. Sources of Contamination

SOURCES	PROCESSES	PRINCIPAL CONTAMINANTS
A. <u>Biological</u>		
Man:		
Respiration	Exhalation, sneezing, coughing, evaporation	CO ₂ , CO, mucus, bacteria, virus
Flatus	Flatulation	H ₂ , H ₂ S, CH ₄
Urine	Micturition, spillage, storage, evaporation	Many acids, urea, ammonia, phenols, inorganic salts
Sweat	Perspiration, evaporation	Ammonia, phenol, acids, inorganic salts
Sebum	Secretion, vaporization	Fats, fatty acids, odoriferous substances and acids, desquamated epithelium
Feces	Defecation, spillage, storage, evaporation	Ammonia, phenols, indole, skatole, methyl mercaptan, paracresol, bacteria
Hair, nails	Depilation, clipping, shaving	Particulate debris
Cerumen	Secretion, vaporization	Odoriferous waxes
Microbes	Indigenous body organisms,	Bacterial debris, possible infectious
B. <u>Nonbiological</u>		
Food, beverages	Spillage, decomposition, regurgitation	Debris, odors, provide substrates for microbial proliferation
Waste disposal systems	Spillage, leakage, decomposition	Debris, odor, noxious gases, microbial proliferation
Construction materials		
Metals	Wear, oxidation, galvanic corrosion	Dust, metallic oxides, H ₂
Plastics	Wear, heat	Dust, phenol, formaldehyde, other noxious vapors

Table 3.2-X. Sources of Contamination, Contd

SOURCES	PROCESSES	PRINCIPAL CONTAMINANTS
Other nonmetals	Wear, decomposition	Dust, substrates for auto-throphic growths
Paints	Wear, vaporization	Dust, toxic organic vapors
Lubricants	Spillage	Aerosol formation, odors
Electronic gear insulation	Corona discharge, ionization, heat	Ozone, ionized air, phenol, formaldehyde
Electrical motors, pumps, batteries	Wear, power generation and conversion	Ozone, ionized air, H ₂

The TLV is the average of the time-weighted concentrations throughout an eight-hour working day. It is based on the toxicological principle that toxic response is proportional to the product of concentration and the duration the concentration is experienced.

The philosophy adopted for the present LSS was to convert the industrial TLV's to space MAC values by using a reducing factor of 10. The MAC approach is considered more practical, since it eliminates "time integration" and therefore makes the monitored results easier to interpret.

The rationale used to arrive at this reducing factor is as follows. The industrial TLV's are time-weighted average values based on a 40-hour week. Continuous exposure would amount to 168 hours per week or 4.2 times as much. An additional factor, provisionally set at about 2.5, is introduced in the hope that it will compensate for the fact that the body does not have an opportunity to "recuperate" during prolonged continuous exposure and that synergism between different toxic materials is possible. The product of these two factors results in a reducing factor of 10. The use of a factor of 10 to convert industrial TLV values to space MAC values would result in a carbon monoxide space MAC of 10 ppm. This reducing factor of 10 appears reasonable and is used to specify maximal acceptable concentration levels from the industrial TLV data. The results are shown in Table 3.2-XVII.

3.2.4.5 Techniques Selected. Established techniques presently in use for closed atmospheric systems show that contaminants can be successfully controlled by a combination of particulate filters, charcoal filters, and catalytic burners.

Table 3.2-XI. Compounds Quantitatively Identified in Submarine Atmospheres

MATERIAL	CHEMICAL FORMULA	TYPE OF SUBMARINE*	HIGHEST CONCENTRATION NORMALLY FOUND
Acetylene	C_2H_2	N	0.5 ppm
Ammonia	NH_3	N	>1 ppm
Carbon Dioxide	CO_2	F, N	1.1%
Carbon Monoxide	CO	F, N	38 ppm
Chlorine	Cl_2	F, N	1 ppm
Freon-12	CCl_2F_2	F, N	70 ppm
"Hydrocarbons" (Other than CH_4)	"HC"	F, N	25 ppm
Hydrogen Fluoride	HF	N	0.3 ppm
Hydrogen	H_2	F, N	1.75%
Methane	CH_4	F, N	118 ppm
Methyl Alcohol	CH_3OH	N	6 ppm
Monoethanolamine	$HOCH_2CH_2NH_2$	N	<1 ppm
Nitrogen	N_2	F, N	80%
Nitrogen Dioxide	NO_2	N	0.1 ppm
Nitrous Oxide	N_2O	N	27 ppm
Oxygen	O_2	F, N	20%
Stibine	SbH_3	F, N	1 ppm
Water Vapor	H_2O	F, N	60% RH
Cigarette Smoke		F, N	0.4 μg /liter

*F = fleet; N = Nuclear

Source: Platt, 1960

Table 3.2-XII. Compounds qualitatively Identified in Trace Amounts
in Submarine Atmospheres

MATERIAL	CHEMICAL FORMULA	TYPE OF SUBMARINE*
Arsine	AsH_3	F
Benzene	C_6H_6	N
1-3-Dimethyl-5-ethylbenzene	$1, 3-(\text{CH}_3)_2-5-\text{C}_2\text{H}_5\text{C}_6\text{H}_3$	N
Ethylene	C_2H_4	N
p-Ethyl Toluene	$1, 4-\text{CH}_3\text{C}_2\text{H}_5\text{C}_6\text{H}_4$	N
Freon-114	$\text{CF}_2\text{ClCF}_2\text{Cl}$	N
Gasoline Vapors	-	F
Hydrogen Chloride	HCl	N
Mesitylene	$1, 3, 5-(\text{CH}_3)_3\text{C}_6\text{H}_3$	N
Propane	C_3H_8	N
Pseudocumene	$1, 2, 4-(\text{CH}_3)_3\text{C}_6\text{H}_3$	N
Sulfur Dioxide	SO_2	F, N
Toluene	$\text{C}_6\text{H}_5\text{CH}_3$	N
o-Xylene	$1, 2-(\text{CH}_3)_2\text{C}_6\text{H}_4$	N
m-Xylene	$1, 3-(\text{CH}_3)_2\text{C}_6\text{H}_4$	N
p-Xylene	$1, 4-(\text{CH}_3)_2\text{C}_6\text{H}_4$	N

*F = fleet; N = Nuclear

Source: Piatt, 1960

Table 3.2-XIII. Trace Contaminants Identified or Tentatively Identified
in Space Cabin Simulator Atmosphere(1)

COMPOUNDS IDENTIFIED BY CHROMATOGRAPHY	CHEMICAL FORMULA	MAXIMUM CONCENTRATION (μ g/liter)
Acetaldehyde	CH_3CHO	0.53
Acetone ⁽²⁾	CH_3COCH_3	2.05
Dimethyl Sulfide	CH_3SCH_3	0.12
Ethyl Alcohol ⁽²⁾	$\text{C}_2\text{H}_5\text{OH}$	16.6
Freon-11 ^(2, 3)	CFCl_3	47.0
Freon-12 ^(2, 3)	CF_2Cl_2	185.0
Freon-22	CHF_2Cl	0.6
Methyl Alcohol	CH_3OH	0.58
Methylene Chloride ^(3, 4)	CH_2Cl_2	2.3
COMPOUNDS SUSPECTED BY CHROMATOGRAPHY		
Acetylene ⁽⁴⁾	C_2H_2	0.18
Benzene	C_6H_6	0.2
Carbon Tetrachloride	CCl_4	0.035
Ethylene Oxide	CH_2OCH_2	0.2
Freon-114 ⁽³⁾	$\text{CF}_2\text{Cl}-\text{CF}_2\text{Cl}$	0.08
Isobutyraldehyde	$(\text{CH}_3)_2\text{CHCHO}$	0.006
Isoprene	$\text{CH}_2:\text{C}(\text{CH}_3)\text{CH}:\text{CH}_2$	0.08
Methyl Ethyl Ketone	$\text{CH}_3\text{COC}_2\text{H}_5$	0.3
Methyl Isobutyl Ketone	$(\text{CH}_3)_2\text{CHCH}_2\text{COCH}_3$	0.31

Table 3.2-XIII. Trace Contaminants Identified or Tentatively Identified in Space Cabin Simulator Atmosphere⁽¹⁾, Contd

COMPOUNDS IDENTIFIED BY CHROMATOGRAPHY	CHEMICAL FORMULA	MAXIMUM CONCENTRATION (μ g/liter)
Methyl Propyl Ketone	$\text{CH}_3\text{COC}_3\text{H}_7$	0.40
Propionaldehyde	$\text{C}_2\text{H}_6\text{CHO}$	0.011
Toluene	$\text{C}_6\text{H}_5\text{CH}_3$	0.13
MATERIALS DETECTED BY CHEMICAL TESTS		
Amonia	NH_3	2.64 ppm
Chloride Ion	Cl^-	1.80 mg/m ³
Chlorine	Cl_2	0.03 ppm
Ozone	o_3	0.013 ppm
Sulfate Ion	$\text{SO}_4^{=}$	1.95 mg/m ³
Sulfur Dioxide	SO_2	0.056 ppm

NOTES: (1) Basis: two men; 17-30 days duration

(2) Introduced, at least in part, by simulator cabin chemicals or equipment which would not be used aboard flight spacecraft.

(3) Detected in only one simulated flight of five.

(4) Detected in two simulated flights of five.

Source: McKee, 1962

Table 3.2-XIV. Atmospheric Contaminants Recovered from AMRL
Environmental Test Chamber

Carbon Dioxide	Freon-11	Toluene
Ethylene	Acetaldehyde	Tetrachloroethylene
Acetylene	Isoprene	Butanol
Propylene	Ethyl Formate	Acetone
Butane-1	Ethyl Alcohol	Acetic Acid
Isobutylene	Ethyl Acetate	Propionic Acid
n-Butane	Benzene	Butyric Acid
	Trichloroethylene	Formaldehyde

Source: Saunders, 1963

Particulate Filters. Particulate filters are needed to remove solid particles from the cabin atmosphere and prevent clogging and contamination of process equipment. Based on studies of lung damage and the possibility of process equipment contamination, a filtering capability of 0.3 micron is desirable. Such filters are commercially available.

Charcoal Filters. Charcoal filters have been used extensively in commercial and military applications for removal of hydrocarbons, trace contaminants, and odors. Activated coconut shell charcoal has high absorption capacity and should be used.

Catalytic Burner. Acceptable concentration levels of carbon monoxide, hydrogen, hydrocarbons, and other trace contaminants must be maintained aboard the spacecraft. These concentration levels will be controlled by a catalytic burner that oxidizes the contaminants at a reasonable temperature in the presence of a catalyst.

Sizing of the catalytic burner depends upon maintaining an acceptable level of 10 ppm of CO. Three principal sources of carbon monoxide are Bosch reactor bleed, leakage from Bosch reactor, and crew metabolic rate into cabin.

The Bosch reactor bleed rate is that required to limit maximum nitrogen concentration, in the recycle gases to 20 percent. Assuming a maximum of 0.05 lb/day introduction of nitrogen into the reactor, 0.19 cfh bleed is required. The purge rate necessary to remove contaminants and maintain concentrations below flammability limits, assuming a shrouded Bosch reactor leakage rate of 0.05 lb/day, is 3 cfh.

Table 3.2-XV. A Compilation of All Contaminants Identified in the Atmospheres of Mercury Spacecraft

CONTAMINANT	FORMULA	CONCENTRATION (ppm)**
Freon-114*	$\text{CF}_2\text{Cl}-\text{CF}_2\text{Cl}$	60-6000
Ethylene Dichloride	$\text{CH}_2\text{Cl}-\text{CH}_2\text{Cl}$	0-40
Toluene*	$\text{C}_6\text{H}_5\text{CH}_3$	3-20
n-Butyl Alcohol	$\text{C}_4\text{H}_9\text{OH}$	0-4
Freon-11	CFCl_3	0-3
Vinyl Chloride	$\text{CH}_2:\text{CHCl}$	0-3
Ethyl Alcohol*	$\text{C}_2\text{H}_5\text{OH}$	0-3
m-Xylene	$\text{C}_6\text{H}_4(\text{CH}_3)_2$	0-3
Vinylidene Chloride*	$\text{CH}_2:\text{CCl}_2$	0-2
Methylene Chloride*	CH_2Cl_2	0-2
o-Xylene	$\text{C}_6\text{H}_4(\text{CH}_3)_2$	0-1
Benzene*	C_6H_6	0-1
Methylchloroform	CH_3CCl_3	0-1
Trichloroethylene	$\text{CHCl}:\text{CCl}_2$	0-1
Acetone	CH_3COCH_3	0-1
Methyl Ethyl Ketone	$\text{CH}_3\text{COC}_2\text{H}_5$	0-1
Methyl Isopropyl Ketone	$\text{CH}_3\text{COC}_3\text{H}_7$	0-1
Ethylene	$\text{CH}_2:\text{CH}_2$	0-1
n-Propyl Alcohol	$\text{C}_3\text{H}_7\text{OH}$	0-1
Acetaldehyde	CH_3CHO	0-1

Table 3.2-XV. A Compilation of All Contaminants Identified in
the Atmospheres of Mercury Spacecraft, Contd

CONTAMINANT	FORMULA	CONCENTRATION (ppm)**
Ethyl Acetate	$\text{CH}_3\text{COOC}_2\text{H}_5$	0-1
Freon-114, unsym.	CFCl_2CF_3	0-1
Methyl Alcohol*	CH_3OH	0-1
1, 4-Dioxane*	$(\text{CH}_2)_4\text{O}_2$	0-1
Cyclohexane*	$(\text{CH}_2)_6$	0-1
Formaldehyde	CH_2O	-
Hexamethylcyclotrisiloxane	$(\text{CH}_3)_6(\text{SiO})_3$	-
Freon-22	CHF_2Cl	-
Freon-23	CHF_3	-
Freon-12	CF_2CCl_2	-
Freon-125	$\text{CF}_3\text{CF}_2\text{H}$	-
Hexene-1	C_6H_{12}	-
Propylene	C_3H_6	-
n-Butane	C_4H_{10}	-
Butene-1	C_4H_8	-
iso-Pentane	C_5H_{12}	-
n-Pentane	C_5H_{12}	-
Propane	C_3H_8	-
n-Hexane	C_6H_{14}	-
2, 2-Dimethylbutane	C_6H_{14}	-

Table 3.2-XV. A Compilation of All Contaminants Identified in
the Atmospheres of Mercury Spacecraft, Contd.

CONTAMINANT	FORMULA	CONCENTRATION (ppm)**
trans-Butene-2	C_4H_8	-
Cis-Butene-2	C_4H_8	-
Ethylene	C_2H_4	-
Acetylene	C_2H_2	-
3-Methylpentane	C_6H_{14}	-
Carbon Dioxide	CO_2	-
p-Dioxene		
Carbon Disulfide	CS_2	-
1-Chloropropane	$CH_3CH_2CH_2Cl$	-
2-Butanol	$CH_3CH_2CHOHCH_3$	-
trans 1,2-Dimethylcyclohexane	$C_6H_{10}(CH_3)_2$	-
Tetrachloroethylene	$CCl_2:CCl_2$	-
p-Xylene	$1,4-(CH_3)_2C_6H_4$	-
Isopropyl Alcohol	$CH_3CHOHCH_3$	-
n-Propylacetate	$CH_3COOC_3H_7$	-
1,1,3 Trimethylcyclohexane	$C_6H_9(CH_3)_3$	-
1,1 - Dimethylcyclohexane	$C_6H_{10}(CH_3)_2$	-
trans 1, me-3, Ethycyclohexane		-
Allyl Alcohol	$CH_2:CHCH_2OH$	-
Sulfur Dioxide	SO_2	-

*These contaminants were common to the atmospheres of the first three U. S. manned orbital flights.

**The values listed represent the approximate minimum concentrations which would have ensued had all the recovered contaminant been dispersed in the free volume of the cabin at one time. A dash indicates that quantitative values were not determined.

Source: Saunders, 1963

Table 3.2-XVI. Total Waste Accumulation/Man-Day

<u>SOLIDS</u>	UNCONTAINED		CONTAINED	
	WEIGHT (grams)	VOLUME (ml)	WEIGHT (grams)	VOLUME (ml)
Misc. Cabin Compounds	0.700	0.720		
Food Spillage (including vomitus)	0.700	0.700		
Desquamated Epithelium	3.000	2.800		
Hair - Depilation loss	0.030	0.030		
Facial shaving	0.050	0.047	0.250	0.233
Nails			0.010	0.010
Sweat Residue	3.000	3.000		
Sebaceous Residue	4.000	4.000		
Saliva Solids	0.010	0.010		
Mucous Solids	0.400	0.400		
Seminal Residue	0.003	0.003		
Fecal Particles	0.025	0.023		
Micro-organisms	0.160	0.140		
Fecal Solids			20.000	19.000
Urine Solids	<u>0.025</u>	<u>0.024</u>	<u>69.975</u>	<u>65.976</u>
TOTALS	12.103	11.897	90.235	85.219
<u>LIQUIDS</u>				
Fecal Water			100.0	100.0
Urine Water			<u>1330.0</u>	<u>1330.0</u>
TOTALS			1430.0	1430.0
<u>GASES</u>				
Flatus		2000.0		
Insensible Water		<u>1,200,000.0</u>		
TOTALS		1,202,000.0		

Table 3.2-XVII. Recommended Maximal Acceptable Concentration for Continuous exposure

CONTAMINANT	MAXIMAL ACCEPTABLE CONCENTRATION (ppm by volume)
Acetaldehyde	20
Acetic Acid	1
Acetone	100
Acetylene	0.05
Acrolein	0.05
Ammonia	10
Amyl Acetate	20
Amyl Alcohol	10
Arsine	0.005
Benzene	2.5
Butyl Alcohol	10
Butyl Cellasolve	5
Carbon Disulfide	2
Carbon Monoxide	10
Carbon Tetrachloride	1
Cresol	0.5
Cyclohexane	40
Decaborane	0.005
1-3 Dimethyl -5 Ethyl Benzene	--
Dimethyl Hydrazine	0.05
Dioxane	10
Ethyl Acetate	40
Ethyl Alcohol	100
Ethylene	3 - 34% (explosive)
Ethylene Dichloride	5
Ethyl Mercaptan	25

Table 3.2-XVII. Recommended Maximal Acceptable Concentration for Continuous Exposure, Contd

CONTAMINANT	MAXIMAL ACCEPTABLE CONCENTRATION (ppm by volume)
Fluorine	0.01
Formaldehyde	0.5
Freon 12	7
Freon 114	100
Hydrazine	0.1
Hydrogen	4.1 - 74.2% (explosive)
Hydrogen Chloride	0.5
Hydrogen Fluoride	0.3
Hydrogen Peroxide, 90%	0.1
Hydrogen Sulfide	2
Indole	5 (based on methyl mercaptan)
Ketone	0.05
Mercury	0.05 mg/m ³
Mesitylene	20
Methane	5.3-14% (explosive)
Methyl Alcohol	20
Methyl Cellosolve	2.5
Methyl Chloroform	50
Methylene Chloride	20
Methyl Ethyl Ketone	20
Methyl Mercaptan	5
Monoethanolamine	0.1
Nitrogen Dioxide	0.5
Nitrous Oxide	2.7

Table 3.2-XVII. Recommended Maximal Acceptable Concentration for Continuous Exposure, Contd

CONTAMINANT	MAXIMAL ACCEPTABLE CONCENTRATION (ppm by volume)
Ozone	0.01
Pentaborane	0.0005
Perchloroethylene	10
Phenol	0.5
Phosgene	0.1
Phosphine	0.005
Propane	2.3-75% (explosive)
Propyl Alcohol	40
Pseudocumene	20
Skatole	5 (based on methyl mercaptan)
Stibine	0.01
Sulfur Dioxide	0.5
Toluene	20
Triaryl Phosphate	0.03
Trichloroethylene	10
Vinyl Chloride	50
Xylene	20

To maintain the level of metabolically generated CO at 10 ppm, a cabin purge rate of 8.7 cfh is required.

To control unexpected areas of high concentration, an emergency purge capability of 20 cfh should be anticipated.

The total air flow through the burner for these three main sources of carbon monoxide is 31.9 cfh, or approximately 1.65 lb/hr.

Since the ambient contaminant problem is not fully predictable, a safety factor of approximately three should be used, giving a nominal flow requirement of 4.95 lb/hr. Added capability of operating at five times required flow rate, or 8.25 lb/hr, should also be available.

Controlling contaminant concentrations within the MAC level requires two catalytic burners for increased system reliability and for backup in case of unforeseen high contaminant concentrations. Additionally, parallel or series flow through the burners should be provided for maximum flexibility.

3.2.5 ATMOSPHERIC STORES. This program did not include the development of a prototype atmospheric storage system. It did, however, include an evaluation of storage techniques and a recommended approach.

3.2.5.1 Evaluation Criteria. Weight and volume were to be kept to a minimum, with maximum reliability and safety. The logistics characteristics, the withdrawal rates of gases from stores, and the quantities of fluids to be stored were to be consistent with the overall LSS specifications. Metabolic oxygen for 17 days operation was specified, to allow for at least two emergency launch attempts in case the oxygen regeneration unit failed. The total storage required was 240 pounds of O₂ and 222 pounds of N₂ for 90 days.

Minimum usage rates were established to evaluate the heat leakage limitations on cryogenic vessels. For this study the minimum usage rate was taken as the allowable cabin leak rate or 0.374 lb/day of O₂ and 0.742 lb/day of N₂.

The rates required to make up for gas escaping through a 0.01-square-foot hole is shown in Figure 3.2-23 as a function of cabin pressure. The cabin pressure decay without make-up gas is shown in Figure 3.2-24. Waste heat and electrical heaters were considered for the rapid withdrawal and heating of cryogenics. About 20,000 Btu/hr of waste heat at 401°F was assumed to be available from an isotope power source. During an emergency repressurization period, about 4.5 kw of electrical power was assumed to be available.

The atmospheric gases could be stored outside or inside the vehicle, and the following factors were considered:

- a. With proper outside placement of stores and orientation of the vehicle, the effective environmental temperature could be lowered by 200°F. This would drastically reduce boiloff of the cryogenic liquids.
- b. Outside storage would require meteorite protection.
- c. For resupply with transfer lines outside, storage vessels could easily be connected to the resupply tank. Inside vessel fill lines would probably be routed to quick disconnects in the air lock.

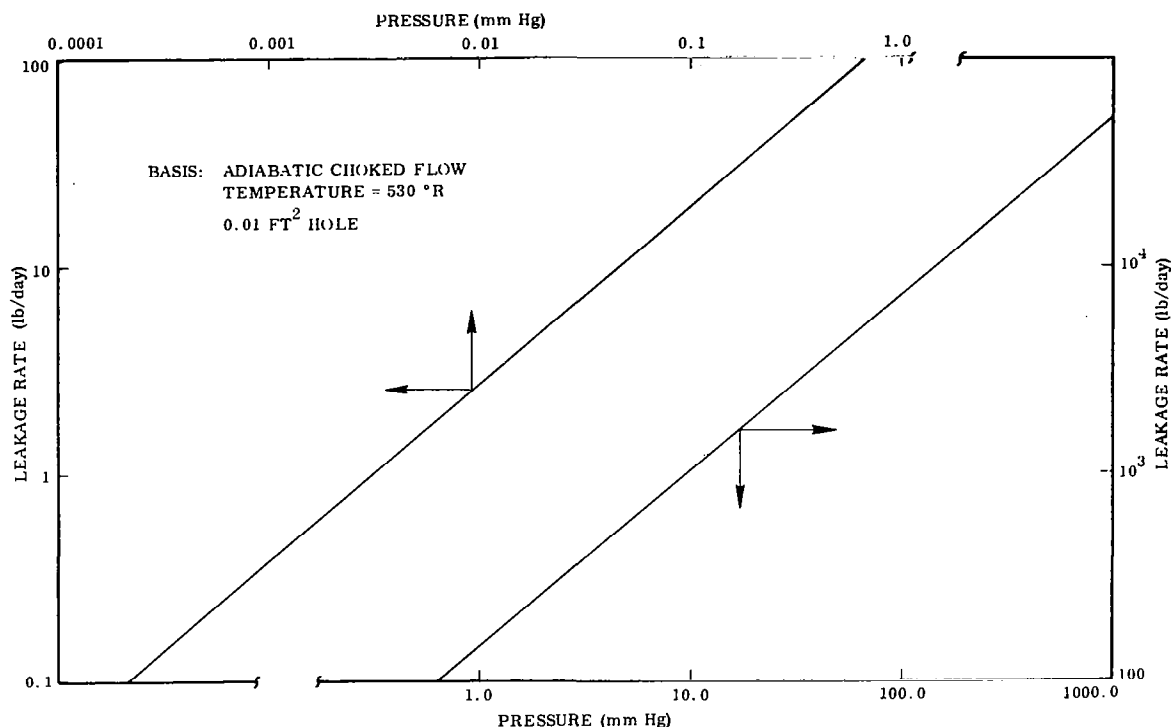


Figure 3.2-23. Cabin Leakage

- d. Outside storage would require undesirable hull penetrations for flow lines and electrical control lines.
- e. Inside storage is the worst case from the standpoint of minimizing boiloff.

3.2.5.2 Types of Storage Considered. The general categories of atmospheric storage methods considered were: high-pressure gaseous storage at ambient temperature; and cryogenic storage at low (subcritical) or moderate (supercritical) pressures and temperatures. Other common storage techniques, such as chemical storage, were eliminated at the outset because they were not applicable.

Cryogenic storage of atmospheric constituents is preferred where any one or more of the following advantages are of primary importance:

- a. High fluid storage density, resulting in increased fluid-carrying capacity for a given vessel size.
- b. Reduced weight penalty, resulting from lower storage pressures and reduced container volume.
- c. Increased safety, due to lower storage and delivery pressures.
- d. Provision of potential refrigeration and cooling sources.

BASIS: ADIABATIC CHOKED FLOW

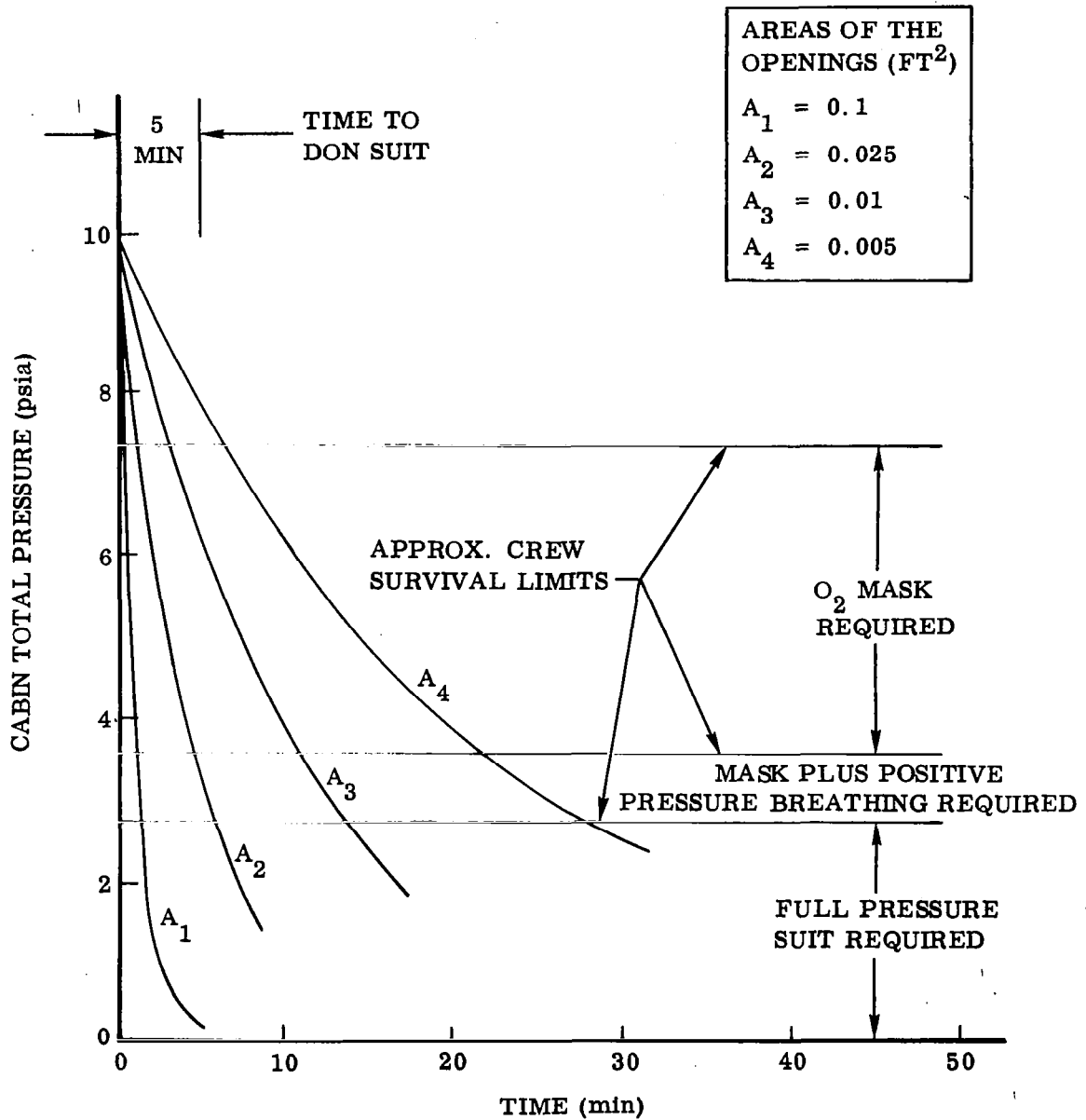


Figure 3.2-24. Cabin Pressure Decay

These advantages are somewhat compromised by:

- a. Severe thermal insulation requirements to minimize fluid boiloff losses and rising pressures during low demand periods of operation.
- b. Control of storage pressure during delivery.
- c. Expulsion of gases only during delivery and standby venting.
- d. Limited withdrawal rate.
- e. Fluid quantity determination.

A number of methods of storing atmospheric constituents cryogenically under zero-g conditions were investigated. Based on a literature survey, the cryogenic storage categories represented by the shaded portions of Figure 3.2-25 were not considered acceptable for LSS atmospheric storage. Fluid expulsion by a positive mechanical method might include the use of diaphragms, bladders, or piston devices, which were considered unreliable with repeated cycling. Systems with partial or full liquid delivery were not applicable because of the low usage rate requirements and the minimum heat leakage that can be designed into cryogenic vessels. The heat content of withdrawn liquid is much lower than that of vapor, and therefore excessive liquid would have to be withdrawn to absorb the vessel heat leakage. The ratio of liquid to vapor withdrawn is proportional to the specific heat inputs. For constant pressure withdrawal at atmospheric pressure, this ratio is about 240 for O_2 and 175 for N_2 . Only if the vessels were placed in a low-temperature environment could liquid delivery be considered.

The two unshaded systems for cryogenic storage were evaluated in some detail. In subcritical storage, the fluid exists as a mixture of liquid and vapor. Heat can be applied to control withdrawal by either a heat-exchange scheme or an electrical heater. The heat input is usually regulated to maintain a constant vessel pressure. Various schemes have been proposed to provide vapor rather than liquid withdrawal and control internal temperature heat transfer, and fluid orientation. These are subject to validation through actual tests in zero-g. The main advantages of subcritical cryogenic storage are low vessel weight and volume, ease of refilling, and better safety, associated with low storage pressures. The disadvantages are: unproven and complex quantity measurement equipment; and high thermal requirements for rapid gas withdrawal.

Supercritical cryogenic storage avoids zero-g phase separation problems. Since the pressure is above the critical point, the fluid is homogeneous, acting as a compressed liquid. The vessel is maintained at constant pressure by heat addition. When the vessel is almost empty, delivery with less heat input, resulting in a lower pressure, may be allowed without liquid phase expulsion. Storage quantity determination is somewhat simpler than for subcritical storage, since the fluid is homogeneous. Withdrawal can be accomplished by opening a control valve to release a measured quantity of fluid. As the fluid leaves the tank, it passes through a heat exchanger and pressure reducer to vaporize the fluid and bring it to the cabin temperature and pressure.

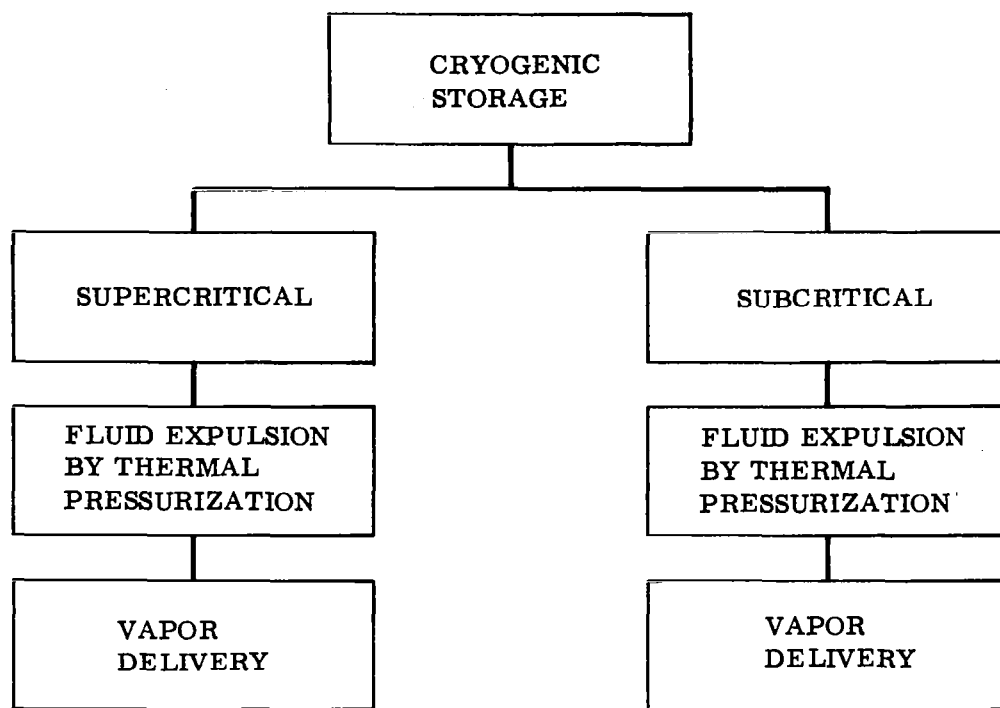


Figure 3.2-25. Cryogenic Storage Methods

The procedures for the design and optimization of high-pressure storage vessels are fairly well known. The optimum design is predicated on obtaining low weight penalties for the storage volume and pressure shell. The volume, and especially the weight requirements, are much larger than for cryogenic storage.

Early consideration was given to the reliability and safety of the number of storage vessels. Approaches that depend on nonreparable, nonredundant elements, such as expulsion bladders, are logical candidates for multiple vessel storage to achieve redundant capacities. However, approaches using potentially reparable elements (immersion or blanket-type heaters, externally mounted flow controls, etc.) and for which tank rupture is not a significant mode of failure will not realize increased reliability by an increased number of vessels. Such approaches attain reliability through good control design employing maximum reparability of the active elements in a system using two to three vessels.

A reliability comparison was made between supercritical and subcritical cryogenic storage systems. No significant difference in the combined reliability and safety potential of the two approaches under zero-g was indicated. Both approaches require essentially the same types of inputs, have equivalent control demands, and must perform similar functions. For example, both require controlled heat inputs to maintain minimum internal pressures. The difference is in level of complexity.

Supercritical vessels control to maintain state, and subcritical vessels to maintain minimum expulsion pressure or reduced boiloff. Both may require some form of mechanical mixing to maintain adequate performance margins. Control of output flow condition was considered more difficult with subcritical storage.

The withdrawal of cryogenics from storage vessels and the subsequent temperature rise to cabin conditions requires heat input. The amount of this heat depends upon the cryogenic storage conditions and cabin conditions. Highest withdrawal rates occur during cabin repressurization, and maximum heat input is required when the vessels are full. (See Figure 3.2-26.) A cabin repressurization from full tanks leaves about 71 percent of the total O₂ stored and about 37 percent of the total N₂ stored left in the tanks. Using an approximate average specific heat input for the O₂ and N₂ from full tanks to these values, the tank heating requirements for delivery were calculated. The total is shown in Figure 3.2-27 as a function of repressurization time.

The minimum withdrawal rates correspond to the cabin leakage rates used to determine the allowable heat leakage into typical supercritical vessels. The allowable heat leakage was

$$q_{O_2} = 0.78 \text{ Btu/hr and } q_{N_2} = 1.49 \text{ Btu/hr.}$$

These values were lower than could be achieved in supercritical vessel design. Therefore, this type of storage was penalized with venting weight losses.

The maximum withdrawal rates from subcritical vessels also require high heating rates. These rates are indicated in Figure 3.2-28. If electrical heat is used for the withdrawal and waste heat for subsequent heating to cabin temperature, the minimum repressurization time is about 1.2 hours.

The minimum withdrawal rates, (i.e., cabin leak rate) give heat leakage values of $q_{O_2} = 1.3 \text{ Btu/hr}$ and $q_{N_2} = 2.4 \text{ Btu/hr}$ for subcritical storage with vapor delivery.

These values do not include the sensible heat required to raise the gases to cabin conditions. Actually, if the delivery lines were integrated with the vessel insulation, a portion of this heat could be included as heat leakage into the vessel.

Gas can be withdrawn from high-pressure storage at as low a rate as desired without heat leakage problems. High rates of withdrawal are also easily accomplished, because of the high pressures that are available to force the gas into the cabin. The Joule-Thompson cooling effect was calculated, to determine if rapid withdrawal resulted in a substantial heating requirement to bring the repressurized cabin air to 70°F. The heating requirement varies with tankage level, but at the worst condition (full O₂ tank at 8000 psi and full N₂ tank at 6000 psi), the values are about 24 Btu/lb of O₂ and 17.5 Btu/lb of N₂. A total repressurization in one hour under these conditions would

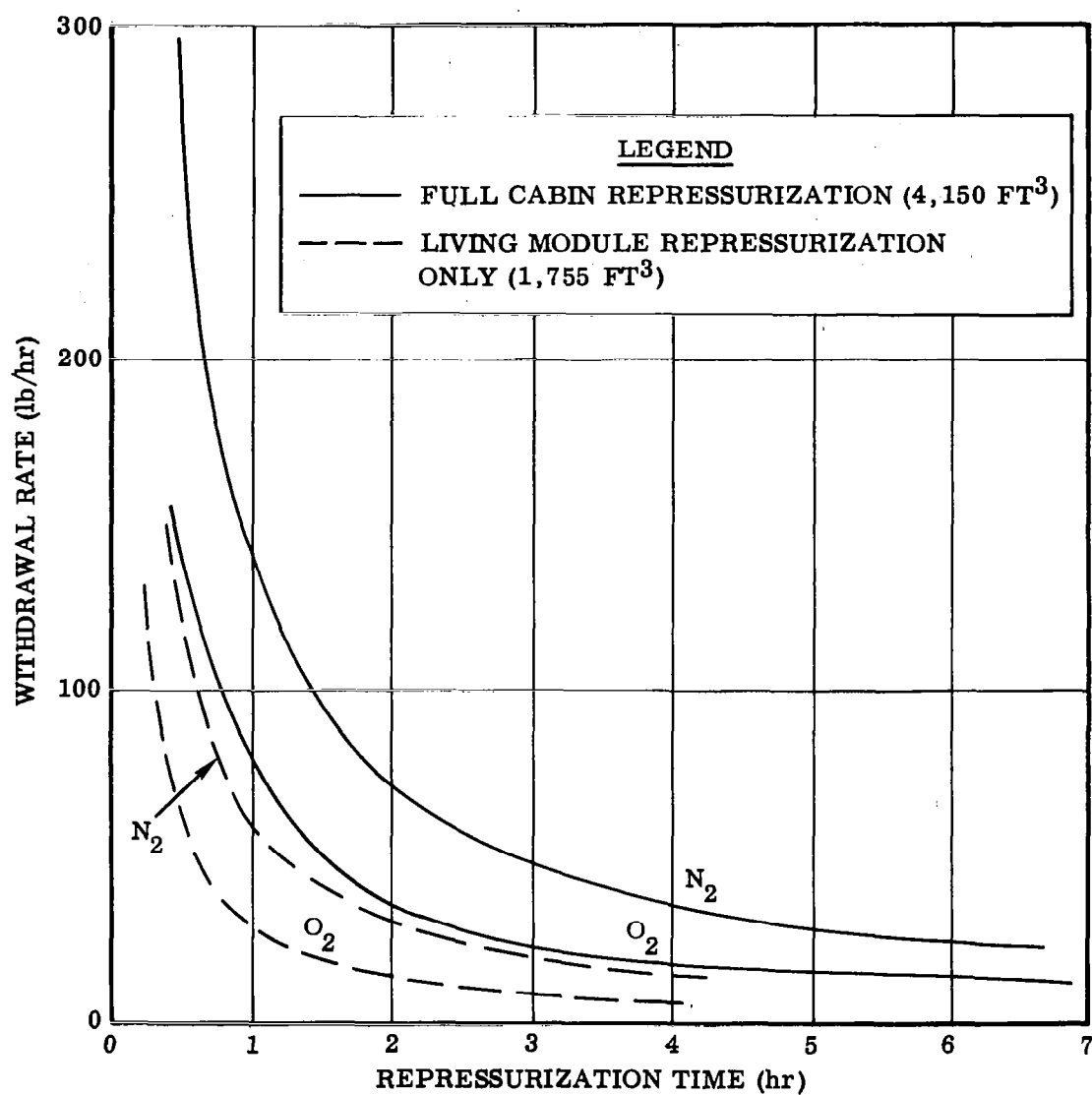


Figure 3.2-26. Withdrawal Rates from Stores During a Cabin Repressurization

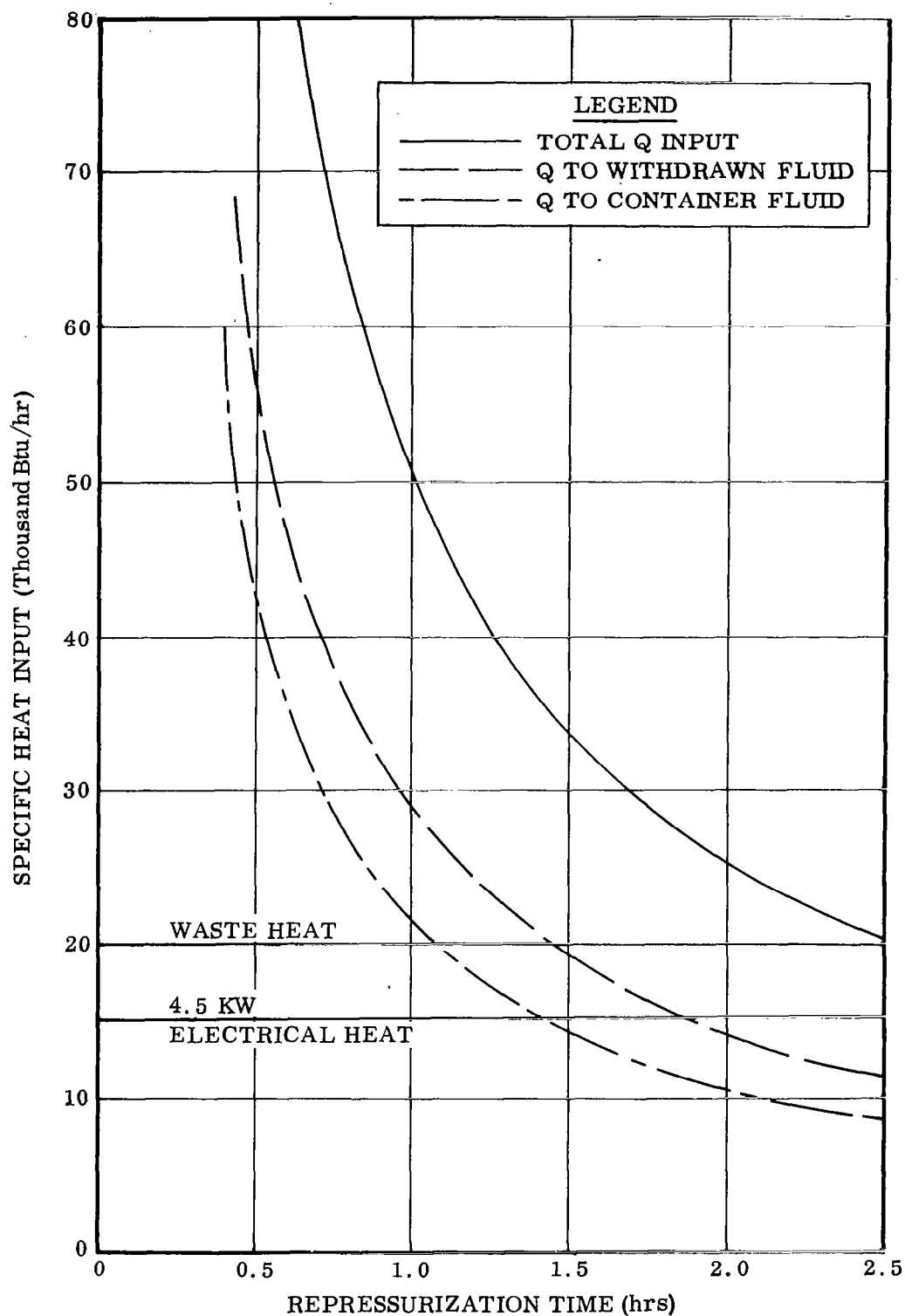


Figure 3.2-27. Repressurization Thermal Input Requirement for Supercritical Storage

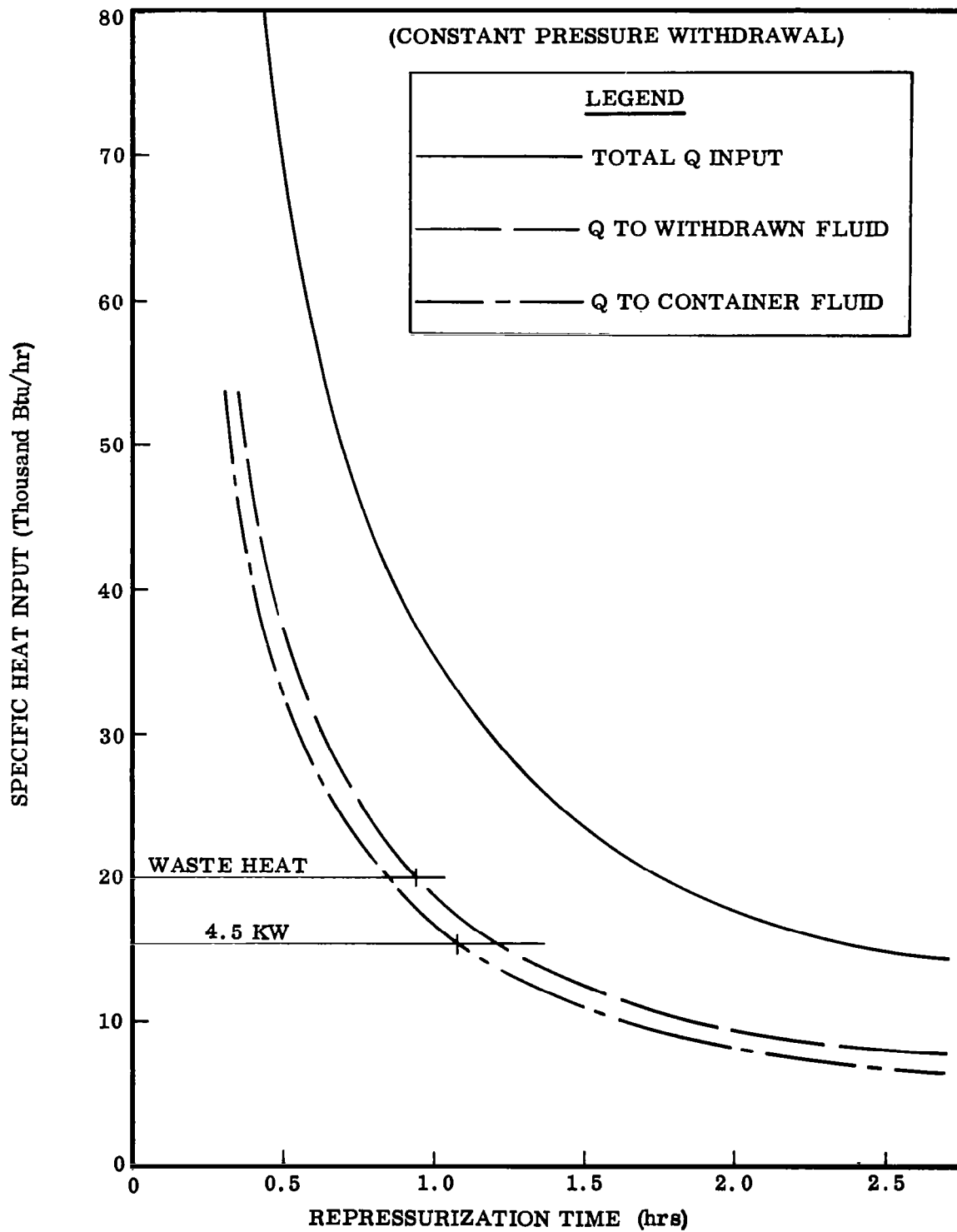


Figure 3.2-28. Repressurization Thermal Input Requirement for Subcritical Storage

require 4150 Btu/hr. The actual heat required would probably be around 3000 Btu maximum and would diminish to zero as the tanks were emptied. This amount could be provided easily by electrical heating or by waste heat.

The logistics of cryogenic and/or gaseous storage vessels without the transfer of the vessels themselves was considered in the selection of a storage technique. During resupply, fluids must be transferred with maximum reliability and safety and minimum weight penalty. Liquid transfer would cause boiloff losses but would be accomplished at low pressures and low total volumetric flows. Gaseous transfer would be possible at cabin temperatures but would require high pressures. If a compressor were not used to pump the gases from the resupply tanks, extremely high pressures would be required in these tanks to accomplish the transfer. Also, gas would have to remain in the resupply tank at the final fill pressure to be returned to earth. Compressors working at the high pressures involved with gaseous storage vessels are quite heavy, power-consuming, and complicated in themselves. Therefore their use was not recommended.

Cryogenic liquid transfer could be used to resupply cryogenic vessels and high-pressure vessels that were empty. A subcritical storage system is slightly better than a supercritical system for this type of resupply. Losses are lower during the resupply of nonempty containers; and zero-g vapor withdrawal from a two-phase mixture, as would exist during filling, is inherent in the storage technique. Hence, a minimum of additional venting plumbing for the fill operation would be needed.

The weights and volumes of some storage systems that were applicable to this LSS are shown in Table 3.2-XVIII. Systems 1 and 2 are high-pressure storage only, and systems 3 through 7 are totally cryogenic. Systems 8 through 11 are combinations of high-pressure and cryogenic storage such that boiloff and repressurization problems are minimized, yet resupply of liquids to refill cryogenic vessels is possible. The weights and volumes of the combined systems are higher than those of the cryogenic systems but lower than those of the high-pressure gas systems.

When exposed to the internal cabin environment, the cryogenic systems are not capable of as low a boiloff as the specified cabin leakage. As a result, vent gases would be lost and an additional expendable weight penalty incurred. Eventually, the weight of this gas lost would surpass the weight of high-pressure containers, which would not require venting. This tradeoff, based on a 90-day resupply, indicated that total cryogenic system weights for up to about seven or eight months duration are lower than those of the high-pressure systems. For missions exceeding this time period, high-pressure storage was lighter.

3.2.5.3 Recommended Flight Storage Technique. A subcritical storage system was recommended for the flight configuration of the LSS (systems 5 and 6 in Table 3.2-XVIII). The weight savings of subcritical over high-pressure storage are substantial, even if the desired low boiloff rates (33.5 lb/mo) cannot be achieved in early development

Table 2.2-XVIII. Weight and Volume Comparison for Atmospheric Storage Containers

NO.	SYSTEM DESCRIPTION	WEIGHT (lb)	VOLUME (ft ³)	COMMENTS
1	Two High-Pressure Gaseous Oxygen Tanks @ 8000 psia ea.	803	7.79	
2	Two High-Pressure Gaseous Nitrogen Tanks @ 6000 psia ea.	776	12.30	
3	Two Supercritical Oxygen Tanks @ 1500 psia ea.	373	6.71	
4	Two Supercritical Nitrogen Tanks @ 1000 psia ea.	279	7.36	
5	Two Subcritical Oxygen Storage Tanks @ 150 psia ea.	273	6.42	
6	Two Subcritical Nitrogen Storage Tanks @ 150 psia ea.	252	7.05	
7	Three Supercritical N ₂ Tanks @ 1000 psia ea.	303		Two tanks on standby
8	One High-Pressure Gaseous Oxygen Tank @ 8000 psia and One Supercritical Oxygen Tank (41.4 lb of O ₂ @ 1500 psia)	727		Supercritical for leakage makeup and air lock repressurization
9	One High-Pressure Gaseous Oxygen Tank @ 8000 psia and One Subcritical Oxygen Storage Tank (41.4 lb of O ₂ @ 150 psia)	709	7.55	Subcritical O ₂ for leakage makeup and air lock repressurization
10	One High-Pressure Gaseous Nitrogen Tank @ 6000 psia and One Supercritical Nitrogen Tank (81.9 lb of N ₂)	591	10.49	Supercritical N ₂ for leakage makeup and air lock repressurization
11	One High-Pressure Gaseous Nitrogen Tank @ 6000 psia and One Subcritical Nitrogen Tank (81.9 lb of N ₂)	581	10.37	Subcritical N ₂ for leakage makeup and air lock repressurization

Table 2.2-XVIII. Weight and Volume Comparison for Atmospheric S

NO.	SYSTEM DESCRIPTION	WEIGHT (lb)	VOLUME (ft ³)
1	Two High-Pressure Gaseous Oxygen Tanks @ 8000 psia ea.	803	7.79
2	Two High-Pressure Gaseous Nitrogen Tanks @ 6000 psia ea.	776	12.30
3	Two Supercritical Oxygen Tanks @ 1500 psia ea.	373	6.71
4	Two Supercritical Nitrogen Tanks @ 1000 psia ea.	279	7.36
5	Two Subcritical Oxygen Storage Tanks @ 150 psia ea.	273	6.42
6	Two Subcritical Nitrogen Storage Tanks @ 150 psia ea.	252	7.05
7	Three Supercritical N ₂ Tanks @ 1000 psia ea.	303	
8	One High-Pressure Gaseous Oxygen Tank @ 8000 psia and One Supercritical Oxygen Tank (41.4 lb of O ₂ @ 1500 psia)	727	
9	One High-Pressure Gaseous Oxygen Tank @ 8000 psia and One Subcritical Oxygen Storage Tank (41.4 lb of O ₂ @ 150 psia)	709	7.55
10	One High-Pressure Gaseous Nitrogen Tank @ 6000 psia and One Supercritical Nitrogen Tank (81.9 lb of N ₂)	591	10.49
11	One High-Pressure Gaseous Nitrogen Tank @ 6000 psia and One Subcritical Nitrogen Tank (81.9 lb of N ₂)	581	10.37

hardware. With 0.5 percent boiloff per day (66 lb/mo), which is obtained commercially, the weight savings amount to about 350 pounds for one-year mission. This boiloff rate should be attainable in future flight hardware. The weight saving achieved by the use of subcritical rather than supercritical tankage is about 150 pounds. In addition, the subcritical technique is potentially more desirable, since it offers better resupply characteristics, lower volume, and greater safety. With sufficient development on subcritical storage, it was felt that its advantages could be realized. The problems to be solved in the development of a subcritical system include minimization of boiloff, tankage level monitoring, and expulsion control.

The desirability of using combined high-pressure and subcritical storage depends primarily on the cabin repressurization time requirements. The studies showed that with the available heat, a complete repressurization from subcritical storage is possible in less than two hours. Partial repressurization would require even less time.

3.3 WATER MANAGEMENT

Components and subsystem arrangements for the water management subsystem were evaluated and selected in a three-phase analysis. The first phase produced the detailed subsystem requirements and evaluation methodology. The second evaluated the basic techniques for water recovery and selected logical candidates for detailed analysis and final selection. The third selected the recovery techniques and general subsystem arrangement to be employed.

3.3.1 PROCESS TECHNIQUES CONSIDERED

3.3.1.1 Requirements and Evaluation Criteria. A water management subsystem in a closed ecology must include means for the storage and reclamation of waste waters as well as the analysis and storage of fresh or reclaimed water. Urine, soiled wash water, and humidity condensate (originating as perspiration, expired water, and evaporative losses from washing) are the three major waste waters that must be purified for reuse. Reclamation of fecal water, although found to be feasible, was rejected, since metabolic water produced was sufficient to make up for water lost in feces in addition to water lost in the water reclaiming processes (in distillation residues and on adsorbents); reclamation of fecal water was considered to unnecessarily complicate the recovery function.

The chief technological problem in a space vehicle water management system lies in effectively purifying waste waters under zero-g conditions to obtain water sufficiently free of dissolved impurities, harmful microorganisms, and disagreeable organoleptic characteristics to be used for human ingestion and washing purposes. Reclamation of water from urine is, of course, most difficult, and any process that can reclaim water from urine can also reclaim water from used wash water or humidity condensate. Thus the major evaluation effort was placed on the capability of the item to process urine.

Water requirements were determined to include water for food and beverage preparation, drinking water, and wash water. The basis for establishing the quantity requirements is found in the crew model. The recovery quantities and rates are further detailed by the daily water balance, which includes both man and machine as a water consumer-producer. The water balance employed is shown in Table 3.3-I. For purposes of making this balance, a maximum allowance was assumed for ingested water, and average values were assumed for urine and fecal water. Recovery efficiencies used were those believed to be obtainable for each of the water recovery subsystems. Guidelines were established to assure that competing techniques and mechanisms would be evaluated on an equivalent basis. Briefly, these guidelines were:

- a. All known water reclamation techniques were to be evaluated, to select a workable set of logical candidates for detail analysis. This initial evaluation was to be based on the capability to process urine.
- b. Detailed analyses were to be made of the selected candidates, including separate tradeoff studies for reclamation of each of the three waste waters. The differences in waste water contamination levels significantly affect the relative advantages of the competitive recovery processes, making separate tradeoff studies a necessity.
- c. Various configurations of an integrated water reclamation system were to be evaluated; e.g., one, two, and three reclamation units for water recovery from the three waste water sources. The results of the initial (separate) tradeoff studies were to be used in devising the various configurations of integrated systems.
- d. All reclamation systems were to be compared on the basis of a normal operating time of 16 hr/day. This was felt to be reasonable and would leave 8 hours each day for daily start-up and shutdown, routine maintenance, possible breakdowns, and extra capacity following breakdown.
- e. Weights and powers believed to be obtainable in future flight systems were to be used in making tradeoffs, since these quantities are of ultimate interest and should thus be the basis for comparison.
- f. Recovery rates, as reported by organizations engaged in water reclamation programs, were, in most cases, lower than those assumed for this particular mission. Hardware weights, powers, etc., were to be scaled up to the following recovery rates.

urine water,	$\frac{13.2 \text{ lb}}{16 \text{ hr}}$	=	0.825 lb/hr
wash water,	$\frac{13.2 \text{ lb}}{16 \text{ hr}}$	=	0.825 lb/hr
humidity condensate,	$\frac{19.6 \text{ lb}}{16 \text{ hr}}$	=	1.22 lb/hr

Table 3.3-I. Water Balance (Basic: 1 Man-Day)

WATER TO AND FROM ASTRONAUT (lb)			
<u>Consumed and Produced</u>		<u>Waste</u>	
In food	0.23	Urine	3.30
For drinking and food preparation	7.65	Fecal water (discarded)	0.25
Metabolically produced	0.72	Discarded in food	0.16
Subtotal	8.60	Humidity condensate	4.89
Wash water	3.30	Subtotal	8.60
TOTAL	11.90 lb	Used wash water	3.30
		TOTAL	11.90 lb

RECOVERED WATER FOR REUSE (lb)			
<u>Amount Recovered</u>		<u>Use of Recovered Water</u>	
From urine	0.95 (3.30) = 3.13	For drinking and food preparation	7.65
From condensate	0.99 (4.89) = 4.84	For washing	3.30
From wash water	0.97 (3.30) = 3.20	For electrolysis	2.10
From Bosch reactor	1.90	Excess	0.02
TOTAL	13.07 lb	TOTAL	13.07 lb

Scaling up was carried out as follows.

1. For hardware weights, scaling factors (Figure 3.3-1) were developed from data received from MRD Division of General American Transportation Corporation on two vapor compression units of differing capacities.
2. Power and heat rejection values were scaled up directly in accordance with recovery rate; i. e. ,

$$\frac{(\text{recovery rate})_2}{(\text{recovery rate})_1} (\text{power})_1 = (\text{power})_2$$

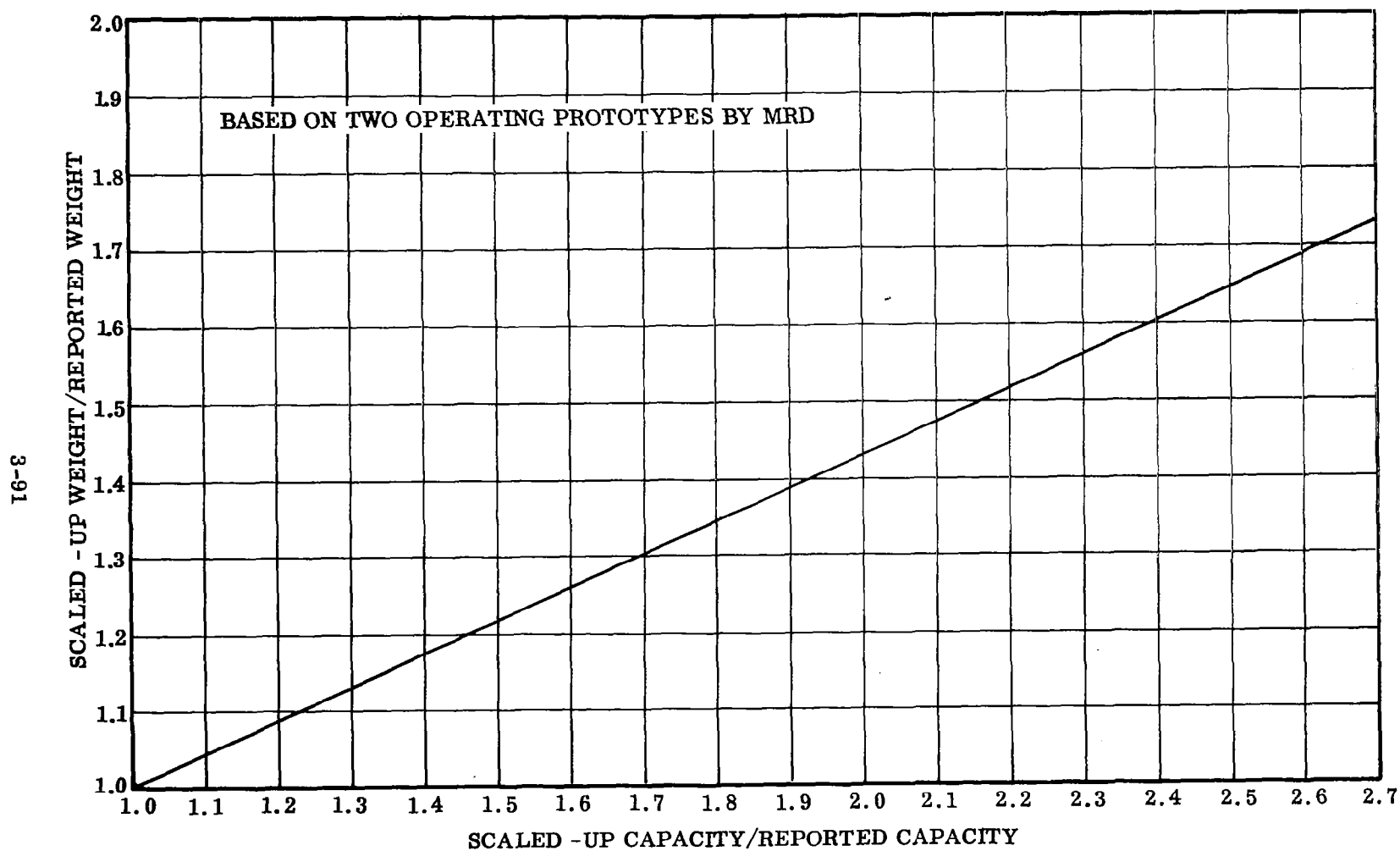


Figure 3.3-1. Scaling Factors for Vapor Compression Units

3. Expendable weights (activated carbon, ion-exchange resin, etc.) were scaled up directly on the basis of the amount of water to be processed; i. e.,

$$\frac{(\text{total weight water processed})_2}{(\text{total weight water processed})_1} (\text{expendable weight})_1 = (\text{expendable weight})_2$$

- g. Processes with recovery efficiencies below 95 percent of water available from urine were to be penalized for the amount of water lost (above 5 percent) due to the inefficiency.
- h. Tanks for storage of waste waters and recovered water were not to be included in system weights, since they are required for all systems.
- i. Tradeoff points were taken as 90 days.
- j. Power, heat supply, and heat rejection penalties were as follows:

Power, 290 lb/kw

Heat supply (from waste heat), $\frac{0.01 \text{ lb}}{\text{Btu/hr}}$

Heat rejection (sensible) $\frac{0.01 \text{ lb}}{\text{Btu/hr}}$

- k. Water retained (unrecoverable) in charcoal filters was to be calculated from

$$\frac{0.70 \text{ lb H}_2\text{O}}{\text{lb charcoal}}$$

- l. Pumping power requirements were to be calculated assuming 50 percent efficiency. This was known to be high for currently available low-volume motor-pumps.

3.3.1.2 Candidate Reclamation Techniques. Originally, 23 techniques or approaches to water recovery were considered worthy of critical evaluation. Sufficient information on each was gathered to permit:

- a. Formation of a schematic (gross mechanization).
- b. Estimates of power and weight.
- c. Definition of current development.
- d. Estimates of development risks and problems involved.
- e. Adaptability to LSS (compatibility).

The results of the evaluation are summarized in Tables 3.3-II and 3.3-III. Of the approaches, 8 were accepted as logical candidates for the LSS. As indicated, each of the 15 rejected approaches were relatively underdeveloped. Most presented major development uncertainties, either technically or schedule, and few promised significant payoffs for the risks involved. On the other hand the 8 selected candidates were relatively well developed and reasonably adaptable to the LSS.

3.3.1.3 Detailed Definition of Candidate Water Recovery Techniques. Detailed information was gathered to permit formation of schematics at the component level and to postulate detailed configurations to define areas of uncertainty as to weight, power, etc. Each approach was defined in terms of its most probable flight configuration. These definitions formed the basis for:

- a. Schematics of the 8 candidate approaches (Figures 3.3-2 through 3.3-9).
- b. Tabulation of the major second-order properties for the 7 approaches capable of processing urine (Tables 3.3-IV through 3.3-VI).
- c. Graphical displays of total weight versus mission duration for the 7 approaches (Figures 3.3-10 through 3.3-12).
- d. Tabulation of the initial reliability appraisal (Table 3.3-VII).

3.3.1.4 Comparison of Candidate Techniques. After the most probable flight configuration for each approach was determined, studies were made of the relative merits of each approach for recovery of urine, wash water, and condensate. The result was a set of rating charts, Tables 3.3-VIII through 3.3-X.

The rating charts show the tradeoff parameters used for selecting the most appropriate approach to water recovery from urine, wash water, and condensate. Each parameter was assigned a relative sensitivity based on its overall importance. Details of each parameter were assigned their contribution to the total sensitivity. Each parameter was assigned a relative rating on the basis of how closely it approached the relative sensitivity value. Relative sensitivity varied for identical parameters, depending upon the waste water.

The overall relative rating for each approach is the sum of the relative ratings for each parameter.

Some parameters in the tables are explained below.

Confidence. The degree of confidence that can be assigned to the assumption that the device as designed can provide processing and product quality within the program schedule. Ratings are based on the degree to which the uncertainties have been explored and inherent process performance margins.

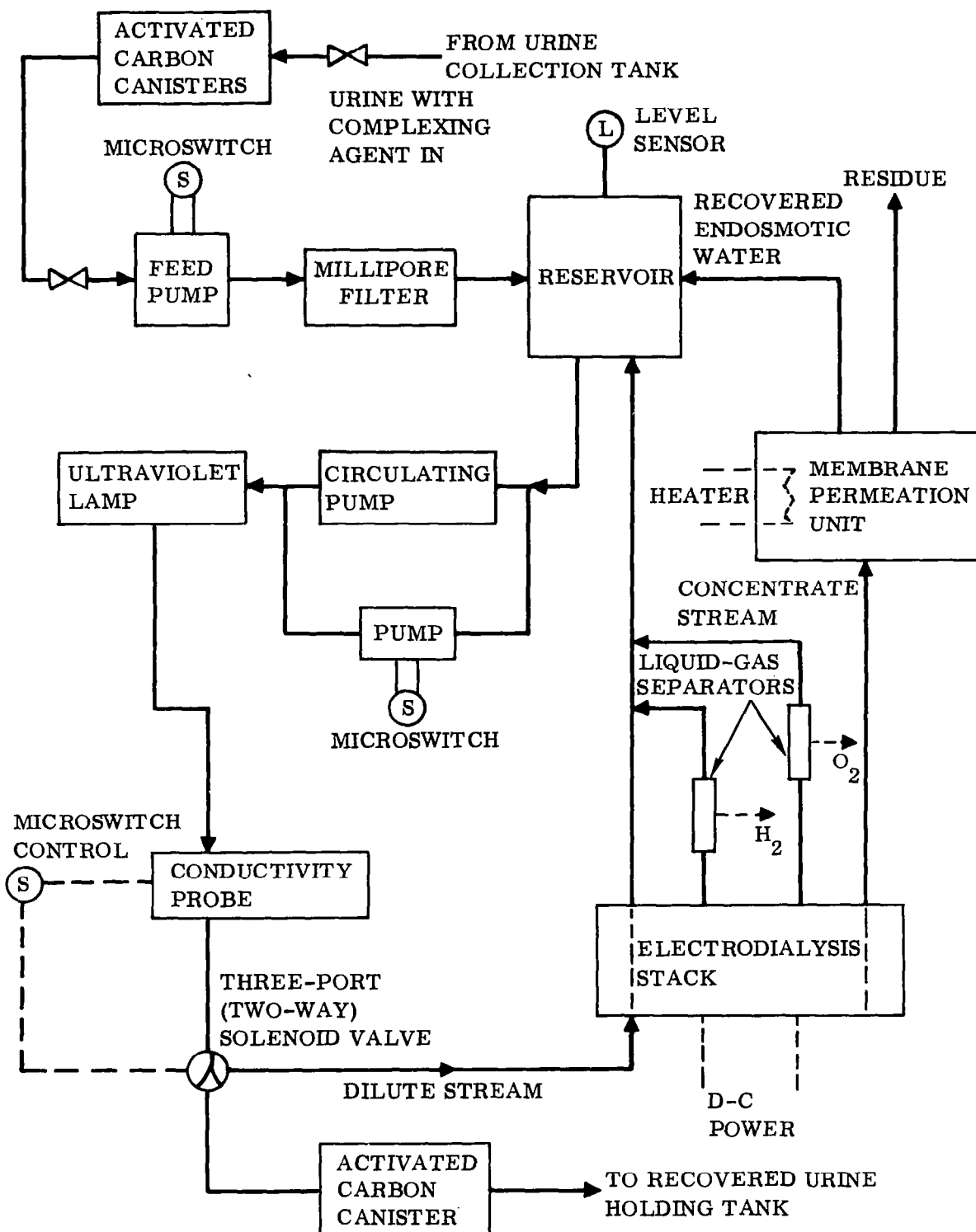


Figure 3.3-2. Electrodialysis - Adsorption

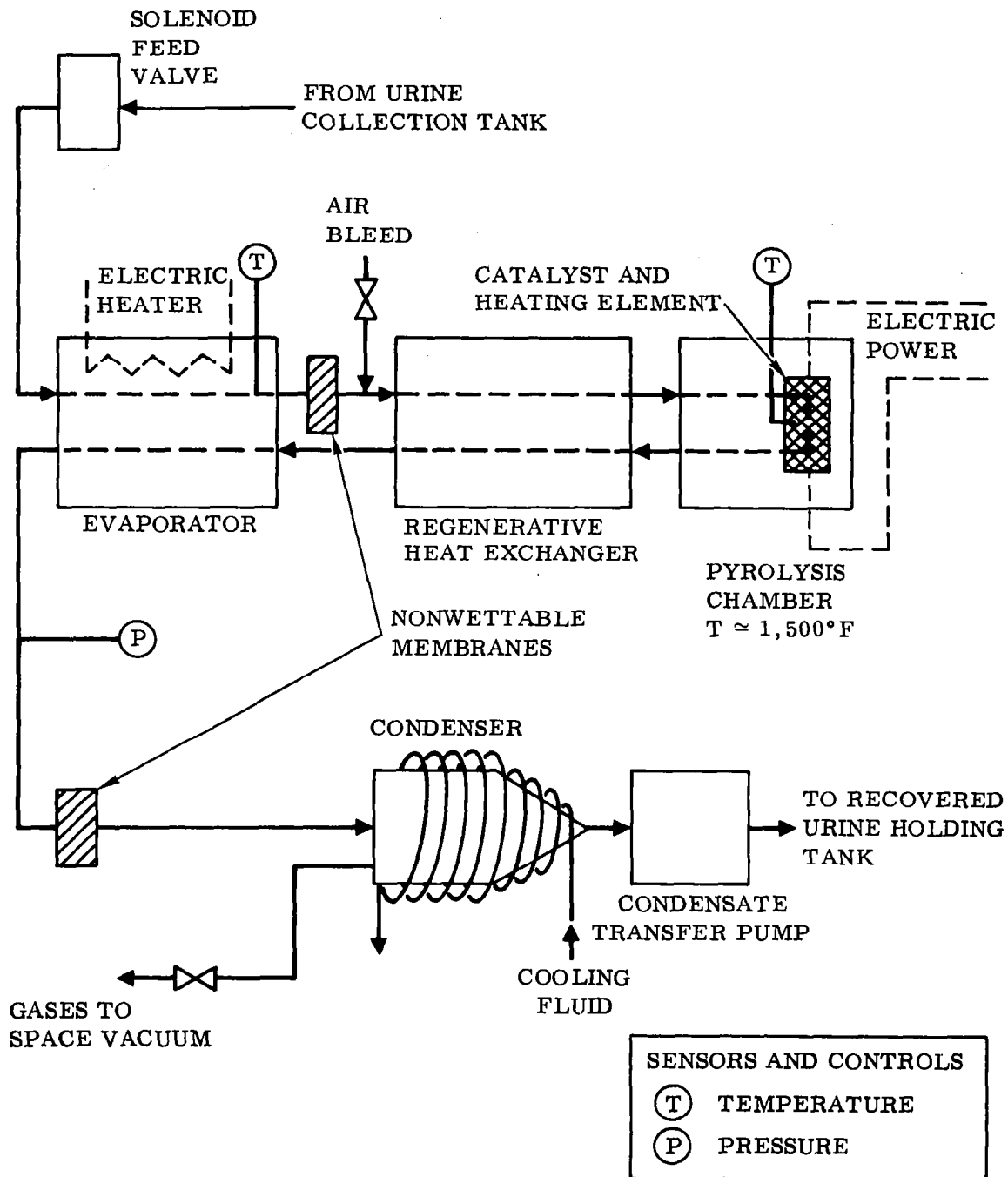


Figure 3.3-3. Vacuum Distillation - Pyrolysis

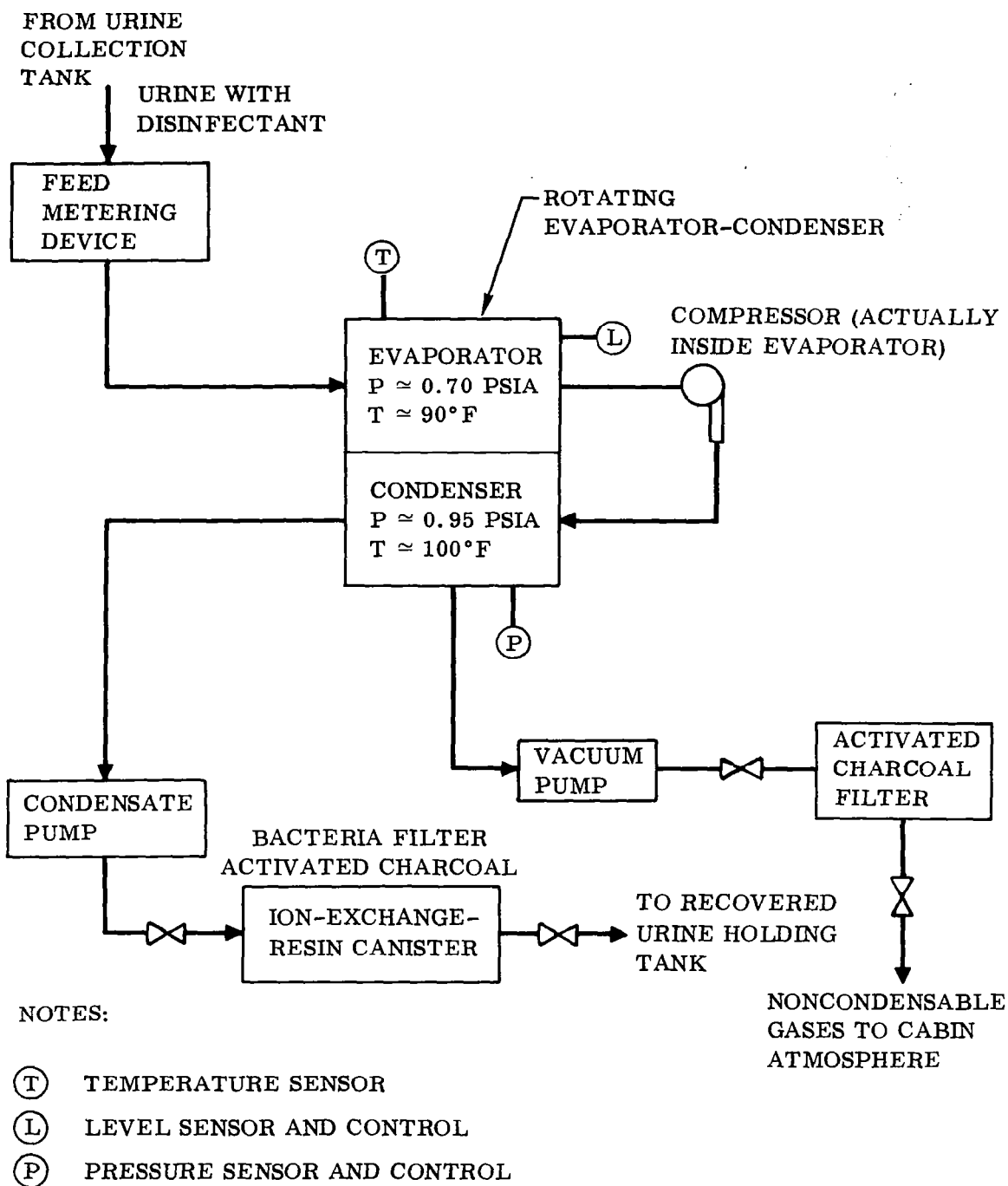


Figure 3.3-4. Vapor Compression

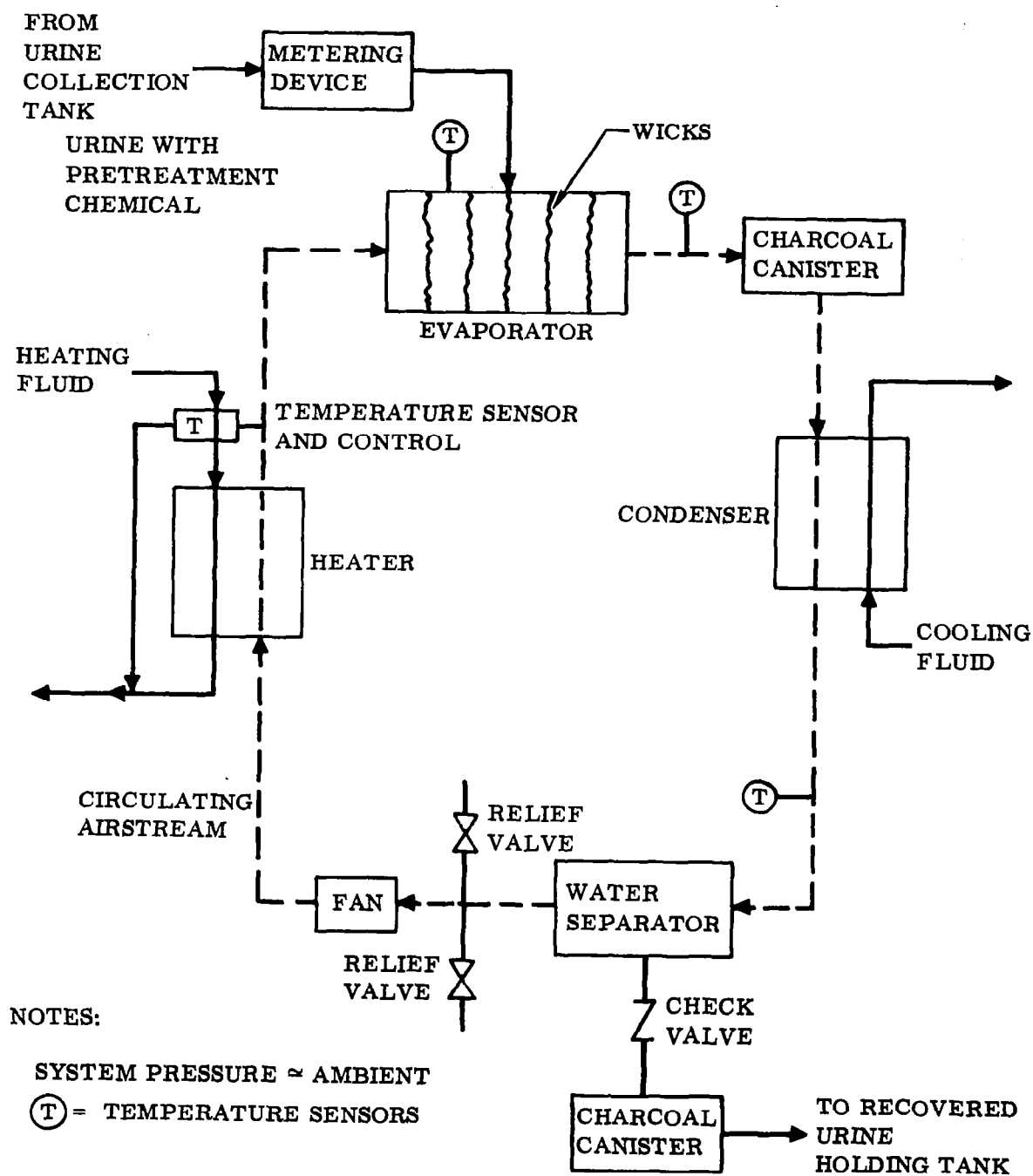


Figure 3.3-5. Waste Heat Air Evaporation

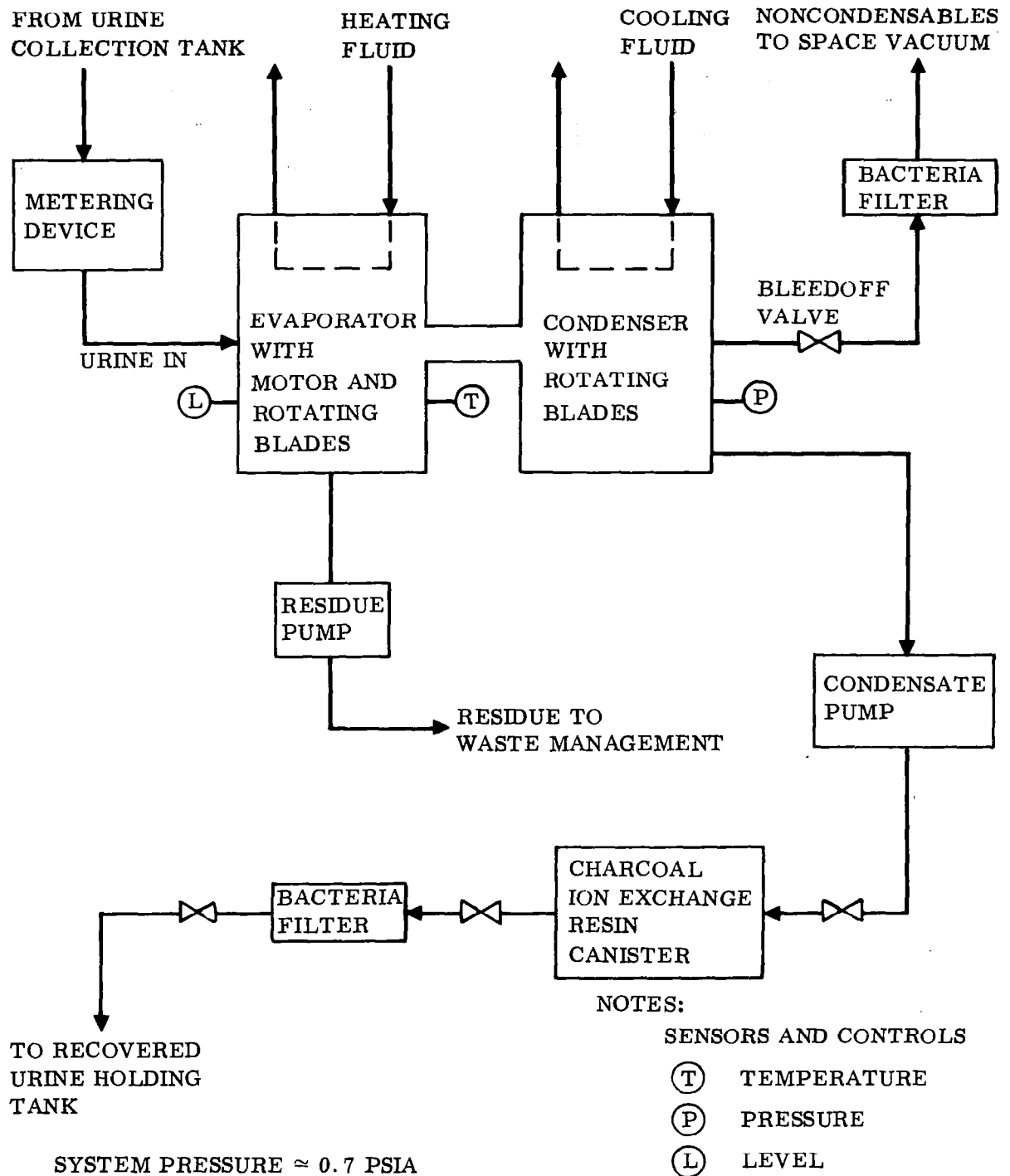


Figure 3.3-6. Waste Heat Vacuum Distillation - Adsorption

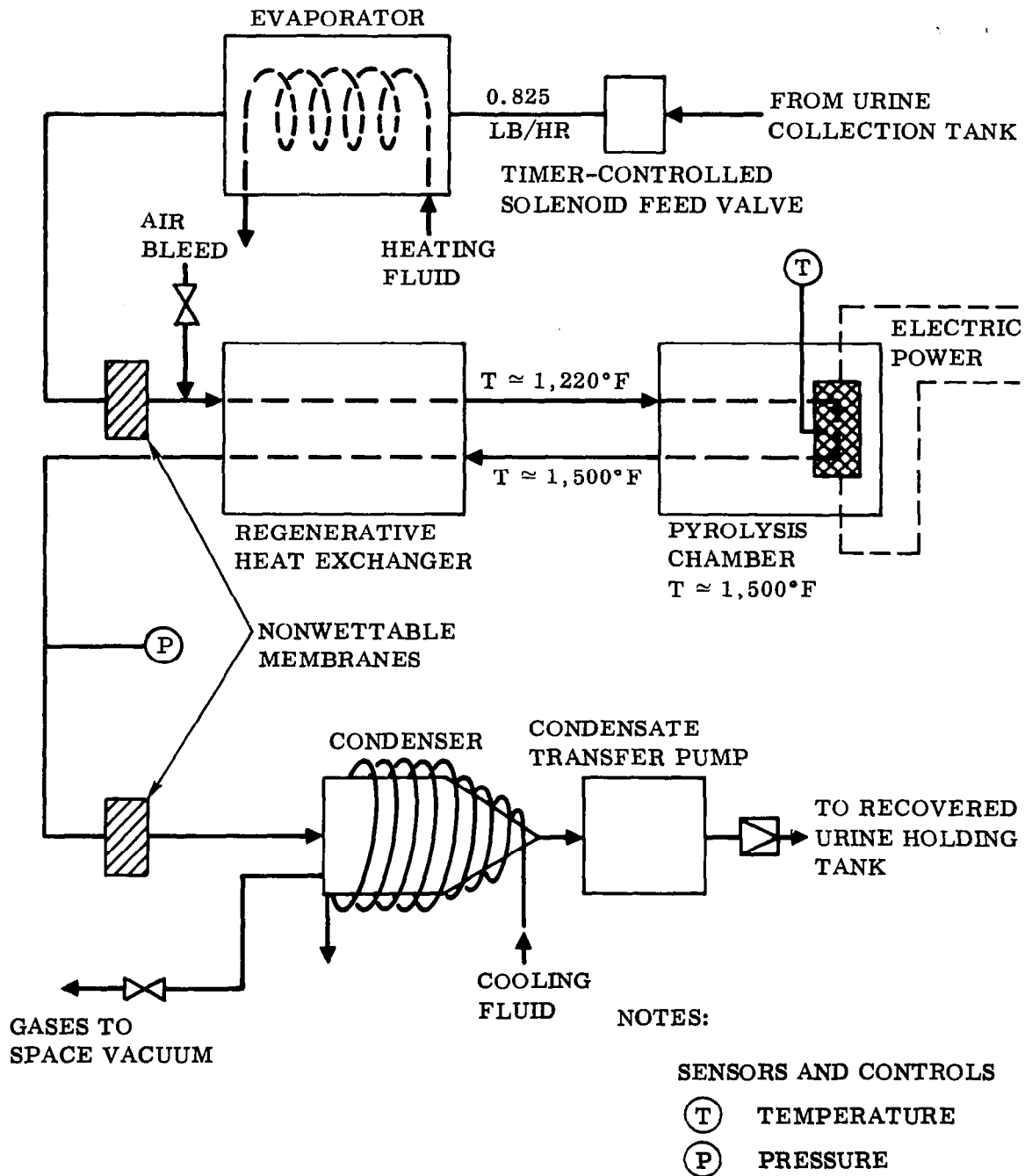


Figure 3.3-7. Waste Heat Vacuum Distillation - Pyrolysis Using Static Evaporator and Condenser

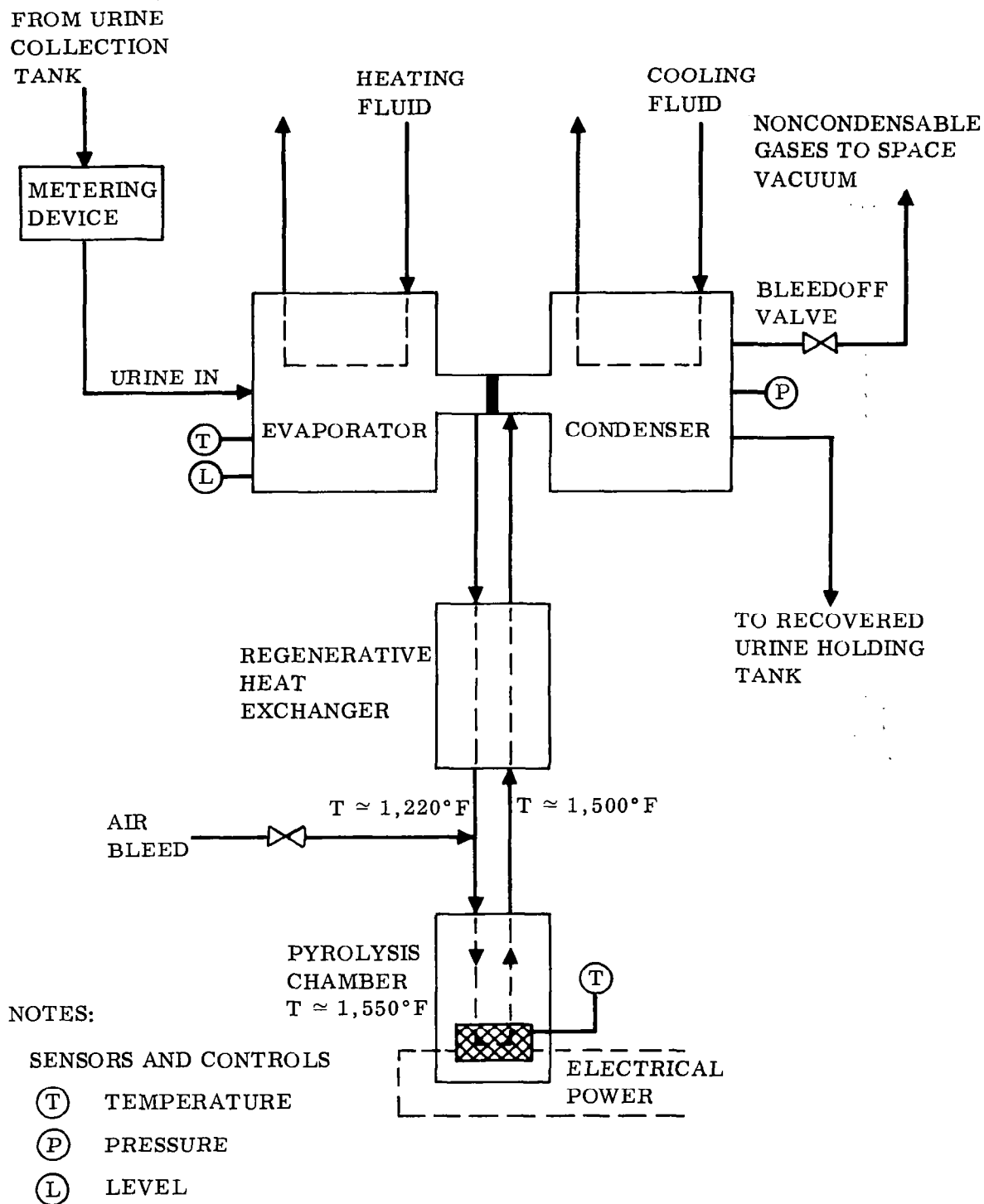


Figure 3.3-8. Waste Heat Vacuum Distillation - Pyrolysis Using Dynamic Evaporator and Condenser

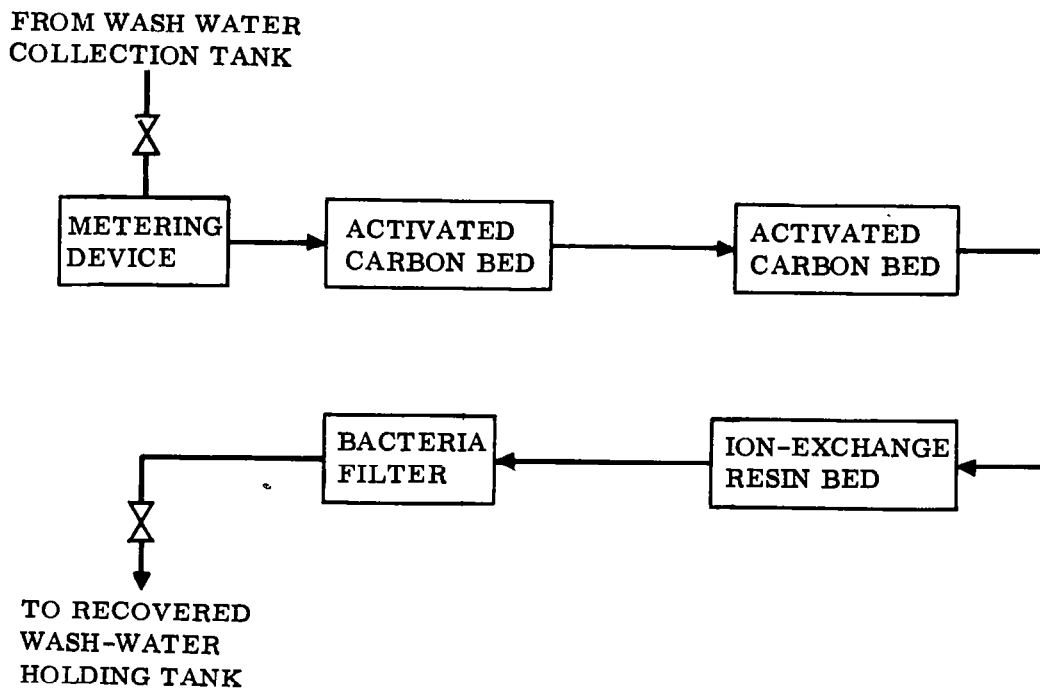


Figure 3.3-9. Multifiltration System

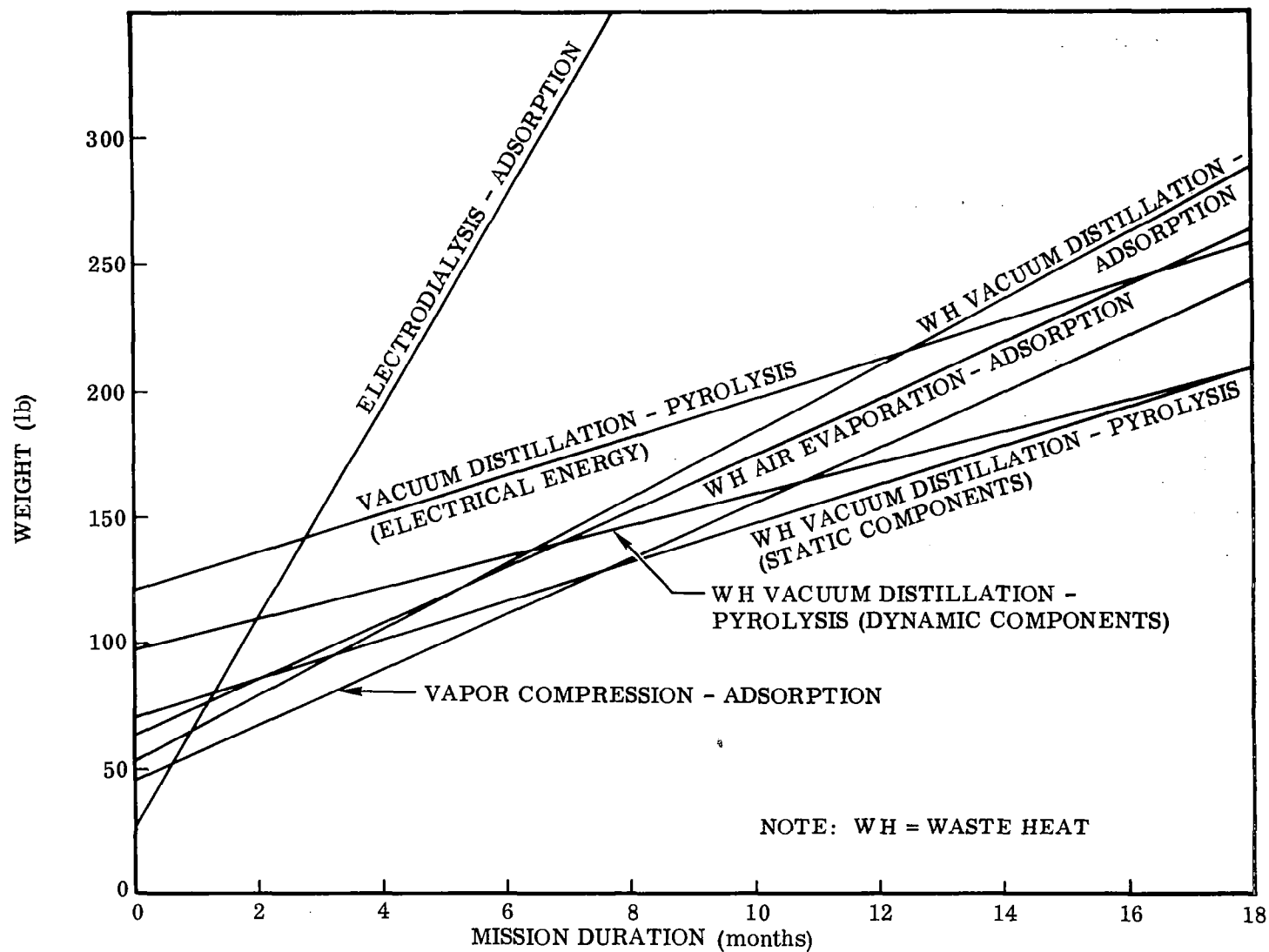


Figure 3.3-10. Total Weight vs. Mission Duration for Urine Reclamation Process

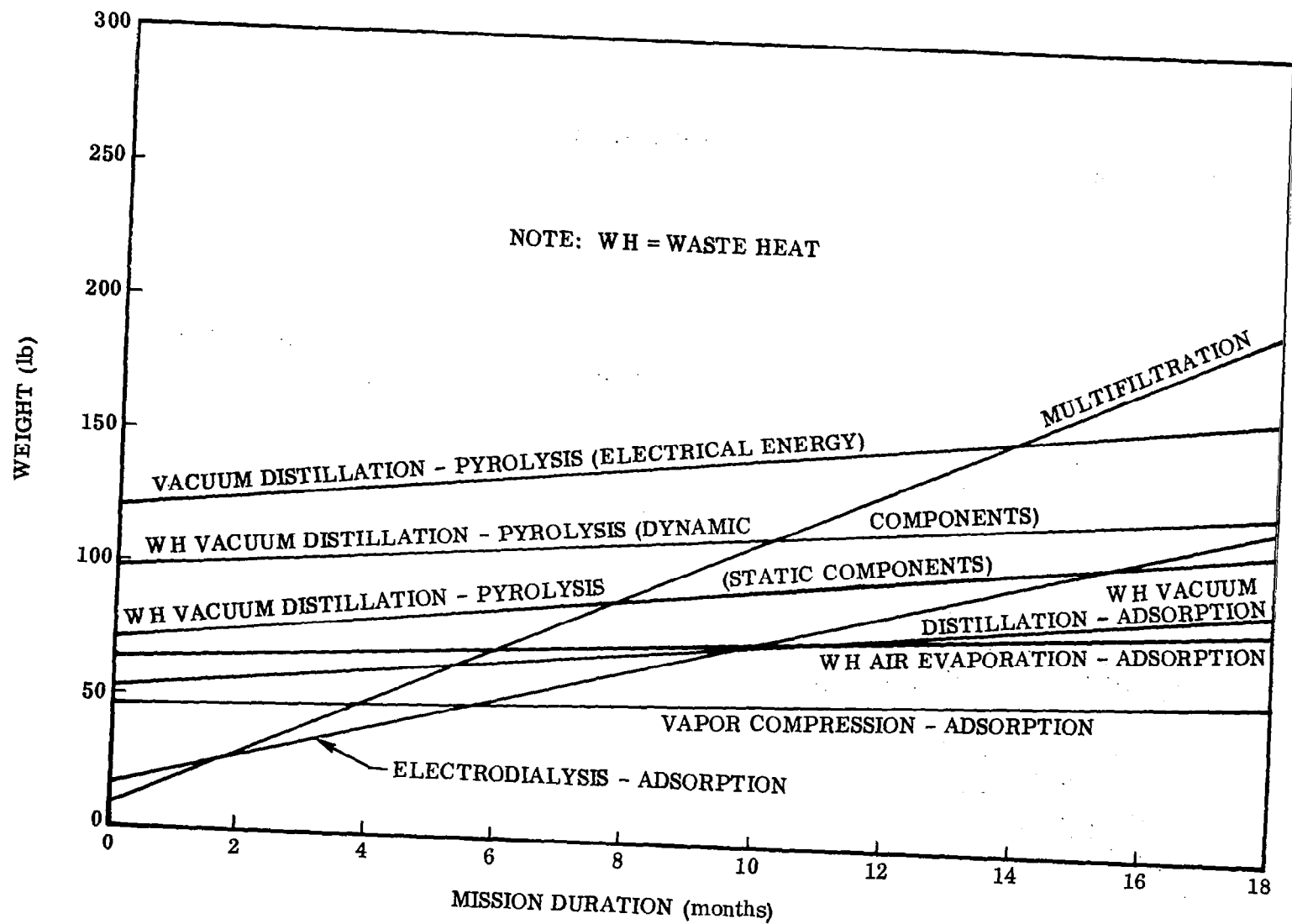


Figure 3.3-11. Total Weight vs. Mission Duration for Water Recovery Processes

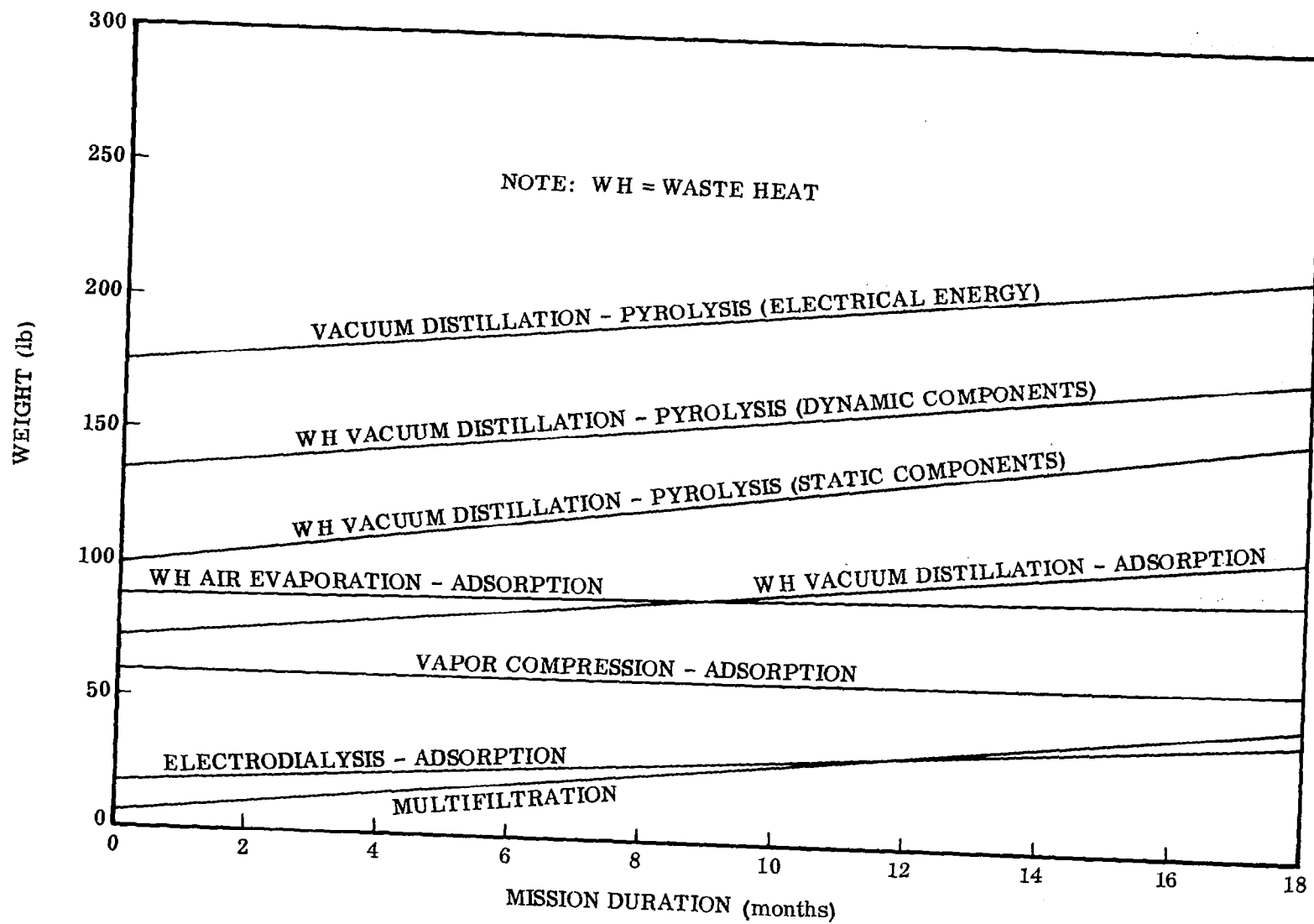


Figure 3.3-12. Total Weight vs. Mission Duration for Humidity Condensate Recovery Processes

Table 3.3-II. Summary of Candidate Water Recovery Techniques Rejected in First Iteration

TECHNIQUE	BASIC PROCESSES	FIRST-ORDER PROPERTIES		SECOND-ORDER PROPERTIES		DEVELOPMENT STATUS			REASONS* FOR REJECTION
		RECOVERY EFFICIENCY (1)	PRODUCT QUALITY (2)	WEIGHT AND POWER (3)	ADAPTABILITY TO LSS (4)	LEVEL OF CURRENT DEVELOPMENT (5)	DEGREE OF DEVELOPMENT UNCERTAINTY (6)	PROBLEMS -- INHERENT AND DEVELOPMENTAL (7)	
1. Reiterative Freezing	Alternate freezing and melting of a column of liquid which concentrates impurities for removal.	50-80%	Uncertain	High	Low	. Undeveloped . Feasibility not established	High	. Complex operation . Mechanization and practicality for "D" G	② 1-7
2. Freeze Crystallization	Progressive purification is achieved by cooling the liquid and removing ice crystals (residual discarded) to form a new liquid, etc., until an acceptable product is achieved.	Low	Uncertain	Very high	Low	. Undeveloped . Feasibility not established	Very high	Same as above	② 1-7
3. Freeze Sublimation (Freeze Drying or Lyophilization)	The liquid is frozen and held under vacuum at reduced temperature; vapor is condensed directly to ice and melted as pure product water.	99%	Good to excellent	High	Fair	. Low . Feasibility partly established	Acceptable	Same as above . Controls additionally complex	3, ⑤ 7
4. Membrane Permeation	Liquid passes through a series of various membranes at a controlled temperature gradient.	Not established	Not established	High	Probably low	. Undeveloped . Feasibility not established	High	Too little known to estimate	1-7
5. Ultrafiltration	Liquid is passed through submicron filter at high pressure (2,000-4,000 psi).	High	Good	Potentially acceptable	Potentially good	. Undeveloped . Feasibility established	High	Mechanization appears long term	⑤ and 7
6. Reverse Osmosis	Liquid is passed through a series of membranes at a controlled pressure gradient (approximately 750 psi on the higher salt concentration).	Low	Potentially good	Potentially acceptable	Unknown	. Undeveloped . Feasibility partly established	High	Membranes not developed, process to reduce expendables not investigated	1, 4, 5, 6, 7
7. Osmotic Process	Osmotic cell produces a driving EMF for an electrodialysis unit.	High	Good	Very high	Unadaptable	Low	High	Requires large quantities of salt water for operation	④ 3-7
8. Thermo Osmosis	No Experimental Data Available								
9. Electrolysis Cell - Fuel Cell	O ₂ and H ₂ obtained by electrolyzing urine is combined to produce pure water and electrical power.	High	Fair to good	Very high	Fair	Prototype has demonstrated feasibility	Acceptable	. Complexity of process . Mechanization complex	3, 4, 7
10. Multi-Effect Evaporation	Liquid is fed to the outer annulus of a multi-stage, tubular, concentrically oriented, rotating evaporator/condenser. Vacuum distillation cycle is repeated.	Potentially acceptable	Not known	No information	Potentially good	Feasibility not established for urine	Unacceptable	Mechanization appears complex	⑥ 2-7
11. Simple Distillation	Distillation at atmospheric pressures at liquid boiling point.	High	Not acceptable	---	---	---	---	---	②

*Major reason circled if one exists.

Table 3.3-II. Summary of Candidate Water Recovery Techniques Rejected in First Iteration, Contd

TECHNIQUE	BASIC PROCESSES	FIRST-ORDER PROPERTIES		SECOND-ORDER PROPERTIES		DEVELOPMENT STATUS			REASONS FOR REJECTION
		RECOVERY EFFICIENCY (1)	PRODUCT QUALITY (2)	WEIGHT AND POWER (3)	ADAPTABILITY TO LSS (4)	LEVEL OF CURRENT DEVELOPMENT (5)	DEGREE OF DEVELOPMENT UNCERTAINTY (6)	PROBLEMS -- INHERENT AND DEVELOPMENTAL (7)	
12. Thermoelectric Distillation	Vacuum distillation employing thermoelectric module for heat transfer between evaporator and condenser.	High	Fair to good	High	Fair	Prototypes in production	Acceptable	High weight and power appear unavoidable	3-7
13. Spray Condenser	Special adaptation of vacuum distillation.	Feasibility not established: initial information, pessimistic							1-7
14. Solvent Extraction	Water content of waste liquid is dissolved from mixture by addition of a liquid solvent nonmiscible with waste liquid.	Feasibility not established for urine in space application							1-7
15. Hydrate Formation	Hydrates, formed by introducing gases to liquid, are filtered. Gas is removed by vaporization and recovered by compression.	Questionable		Feasibility for urine and space application not established					1-7

Table 3.3-III. Summary of Candidate Water Recovery Techniques Accepted in First Iteration

TECHNIQUE	BASIC PROCESSES	FIRST-ORDER PROPERTIES		SECOND-ORDER PROPERTIES		DEVELOPMENT STATUS			REASONS* FOR ACCEPTANCE
		RECOVERY EFFICIENCY (1)	PRODUCT QUALITY (2)	WEIGHT AND POWER (3)	ADAPTABILITY TO LSS (4)	LEVEL OF CURRENT DEVELOPMENT (5)	DEGREE OF DEVELOPMENT UNCERTAINTY (6)	PROBLEMS -- INHERENT AND DEVELOPMENTAL (7)	
1. Electrodialysis Adsorption	Essentially a step process in which a complexing agent precipitates urea, charcoal removes additional organic constituents, and demineralization takes place by electrodialysis (migration of ions through alternate anion-cation membranes).	Demonstrated > 96% but potentially < 98%	Good	Acceptable (expendables are high)	Good	Operating (government contract)	Acceptable	. Mechanisms are complex . Membranes uncertain . Reduction of expendables	2, 4, ⑤ 6
2. Vacuum Distillation Pyrolysis (Electrical)	A two-step process in which the product water of low-temperature, low-pressure distillation is further purified in a high-temperature catalytic oxidation and condensation. Liquid-gas separation by membrane barriers.	Potentially > 95%	Excellent	Very high	Fair to good	Operating breadboard (government contract)	Acceptable	. Power reduction . Waste solids . Collection and disposal	② 5, 6
3. Vapor Compression Adsorption (Compression Distillation)	A two-step process in which a thermally efficient vacuum distillation (vaporization/condensation heat exchanger with vaporization accomplished at the higher pressure and thus higher temperature) process is employed in series with multifiltration. Centrifugal gravity simulation.	Potentially > 95%	Good to excellent	Low	Good	Several operating prototypes (government contract)	Acceptable	. High concentration of dynamic machinery . Liquid seals . Dynamic transfer mechanisms for liquid and electrical power . Pressure controls	③ 2-6
4. Air Evaporation Adsorption (Waste Heat)	Essentially a one-step process in which heated air is passed across an evaporator (liquid held in a wicking matrix) and condenser in an ambient-pressure (closed) air loop. Both the saturated air and the product water is filtered through charcoal beds.	Potentially > 95% and possibly > 98%	Good to excellent	Acceptable	Good to excellent	Operating breadboard (company-sponsored)	Acceptable	. Expendables V-dome . Feed control	④ 1-7
5. Vacuum Distillation Adsorption (Waste Heat)	A two-step process in which the product water of a low-temperature, low-pressure distillation is further purified by multifiltration.	Potentially > 95% but < 98%	Good to excellent	Acceptable	Good	Operating breadboard (company-sponsored)	Acceptable	. Waste solids collection and disposal . Controls . Zero-g rotating equipment	1-6
6. Vacuum Distillation Pyrolysis (Waste Heat-Static)	Same as for Technique 2 except waste heat instead of electrical power is employed in evaporator. (Static refers to liquid-gas separation by membrane barriers.)	Potentially > 95%	Excellent	Acceptable	Fair to good	Operating prototype (government contract)	Acceptable	. Waste solids collection and disposal	2, 5

*Major reason circled if one exists.

Table 3.3-III. Summary of Candidate Water Recovery Techniques Accepted in First Iteration, Contd

TECHNIQUE	BASIC PROCESSES	FIRST-ORDER PROPERTIES		SECOND-ORDER PROPERTIES		DEVELOPMENT STATUS			REASONS FOR ACCEPTANCE
		RECOVERY EFFICIENCY (1)	PRODUCT QUALITY (2)	WEIGHT AND POWER (3)	ADAPTABILITY TO LSS (4)	LEVEL OF CURRENT DEVELOPMENT (5)	DEGREE OF DEVELOPMENT UNCERTAINTY (6)	PROBLEMS -- INHERENT AND DEVELOPMENTAL (7)	
7. Vacuum Distillation Pyrolysis	Similar process for Technique 6, except that dynamic refers to centrifugal gravity simulation at condenser-evaporator.	Potentially 95%	Excellent	High	Fair	No system hardware Components operating in various prototypes	Acceptable	Same as for Technique 3	2, 5
8. Multifiltration	Essentially same as second-stage purification of Techniques 3 and 5. Liquid is pumped through a series of charcoal filters, ion-exchange resin bed, and bacteria filter. When employed alone, this is not adequate for urine.	Demonstrated > 95% but < 98%	Good to excellent (urine poor)	Low	Good	Operating prototypes (government contract)	Very low	Production control to assure no channelization of filters	1-7 Competitive only for wash and condensate

Table 3.3-IV. Estimated Weights of Urine Recovery Systems*

	ELECTRO- DIALYSIS ADSORPTION	VACUUM DISTILLATION PYROLYSIS (ELECTRICAL ENERGY)	VAPOR COMPRESSION ADSORPTION	WH AIR EVAPORATION ADSORPTION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM- DISTILLATION PYROLYSIS STATIC EVAPORATOR	DYNAMIC EVAPORATOR
Peak power, watts	41	321	44	39	35	113	136
Average power, watts	12	321	44	39	35	106	131
Volume, ft ³	4.0	2.8	2.2	4.5	2.5	2.8	4.0
Hardware weight	15.2	17.0	31.8	25.7	25.0	17.0	36.7
Power penalty	11.8	93.0	12.8	11.3	10.2	32.8	39.4
WH penalty	--	--	--	12.8	8.5	8.5	8.5
Heat rejection penalty	0.4	11.0	1.5	14.1	9.7	12.1	13.0
Expendable weight	85.6	23.3	22.9	33.5	29.1	23.3	19.0
Weight added if recovery < 95%	39.2	--	10.2	--	10.2	--	--
Total Weight, lb	152.2	144.3	79.2	97.4	92.7	93.7	116.6

* Basis: Four men at 3.3 lb/man-day; 90 days; recovery rate 0.825 lb/hr.

NOTE: WH = waste heat

Table 3.3-V. Estimated Weights of Wash Water Recovery Systems*

	MULTI- FILTRATION	ELECTRO- DIALYSIS ADSORPTION	VACUUM DISTILLATION PYROLYSIS (ELECTRICAL ENERGY)	VAPOR COMPRESSION ADSORPTION	WH AIR EVAPORATION ADSORPTION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM DISTILLATION STATIC EVAPORATOR	WH VACUUM PYROLYSIS DYNAMIC EVAPORATOR
Peak power, watts	10	27	321	44	39	35	113	136
Average power, watts	10	8	321	44	39	35	106	131
Volume, ft ³	2.1	1.8	2.0	2.0	2.5	2.0	2.0	4.0
Hardware weight	6.0	8.8	17.0	31.8	25.7	25.0	17.0	36.7
Power penalty	2.9	7.8	93.0	12.8	11.3	10.2	32.8	39.4
WH penalty	--	--	--	--	12.8	8.5	8.5	8.5
Heat rejection penalty	0.3	0.3	11.0	1.5	14.1	9.7	12.1	13.0
Expendable weight	31.0	17.7	7.4	2.3	3.5	6.5	7.4	6.0
Total Weight, lb	40.2	34.6	128.4	48.4	67.4	59.9	77.8	103.6

* Basis: Four men at 3.3 lb/man-day; 90 days; recovery rate 0.825 lb/hr

Note: WH = waste heat

Table 3.3-VI. Estimated Weights of Humidity Condensate Recovery Systems*

	MULTI- FILTRATION	ELECTRO- DIALYSIS ADSORPTION	VACUUM DISTILLATION PYROLYSIS (ELECTRICAL ENERGY)	VAPOR COMPRESSION ADSORPTION	WH AIR EVAPORATION ADSORPTION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM DISTILLATION STATIC EVAPORATOR	WH VACUUM PYROLYSIS DYNAMIC EVAPORATOR
Peak power, watts	10	27	475	65	58	52	167	201
Average power, watts	10	8	475	65	58	52	157	194
Volume, ft ³	1.0	1.5	2.2	2.2	2.5	2.2	2.2	4.2
Hardware weight	3.3	9.1	20.6	38.4	31.1	30.2	20.6	44.4
Power penalty	2.9	7.8	138	18.9	16.7	15.1	48.5	58.3
WH penalty	-	-	-	-	18.9	12.6	12.6	12.6
Heat rejection penalty	0.3	0.3	16.3	2.2	20.8	14.4	17.9	19.2
Expendable weight	7.3	4.2	6.6	0.5	1.0	6.6	8.6	7.1
Total Weight, lb	13.8	21.4	181.5	60.0	88.5	78.9	108.2	141.6

*Basis: 19.6 lb/day; 90 days; recovery rate 1.22 lb/hr

Note: WH = waste heat

Table 3.3-VII. Reliability Appraisals for Eight Approaches to Waste Water Processing (H₂O Recovery)

PROCESS	STRENGTH	WEAKNESSES
1. Electrodialysis	H ₂ O output quality control is partially closed-loop.	Multiple-pass system. Most complex system. Output contamination is a likely result of active control elements as well as passive elements.
2. Vacuum Distillation Pyrolysis (Electrical)	Single-pass process. Process control is positive. Output H ₂ O contamination unlikely. Cabin contamination unlikely.	Requirement for operation at less than ambient introduces sealing problems. Zero-g capability condenser, separator uncertain. Evaporator clogging uncertainties.
3. Vapor Compression	Same as 5, although process is somewhat more complex.	Same as 5. Additional control sensitivity required for distillation compression ratio.
4. Air Evaporation (WH)	Single pass process. Process simplicity. Process operates at ambient (approx.).	Process "controls" (bacterial) are open-loop (i.e., passive elements filter and/or chemical agent failures are likely to produce contaminated output). Input flow control may be critical.
5. Vacuum Distillation (Adsorption WH)	Single-pass process. Process simplicity.	Same as 4. Sealing problems introduced by operation below ambient.
6. Vacuum Distillation Pyrolysis (WH) Static Components	Same as 2, although vaporization control may be more difficult.	Same as 2.
7. Vacuum Distillation Pyrolysis (WH) Dynamic Components	Same as 2.	Rotating evaporator and condenser introduce rotating sealing problems; seals required to maintain partial vacuum in unit.
8. Multifiltration (Condensate or Wash)	Predominantly passive elements. Process "safety margins" can be directly achieved by element sizing. Repair simplicity. No energy transfer.	Process "controls" are open-loop. Input flow control problems are present but relatively slight.

Table 3.3-VIII. LSS Ratings of Water Recovery/Urine Processing Systems

TRADEOFF PARAMETER	RELATIVE SENSITIVITY (S _R) OF PARAMETER (H ₂ O RECOVERY)		RELATIVE RATING					
	ELECTRO- DIALYSIS	ELECTRICAL VACUUM DISTILLATION PYROLYSIS	VAPOR COMPRESSION ADSORPTION	WH AIR EVAPORATION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM DISTILLATION PYROLYSIS (STATIC)	WH VACUUM DISTILLATION PYROLYSIS (DYNAMIC)	
I. FIRST-ORDER PROPERTIES								
A Confidence (Degree of development and performance margins)	22	15.75	11.70	19.20	18.25	17.10	11.70	17.40
B Contribution to advance- ment of the state of the art	3	2.7	2.4	2.1	2.7	2.25	2.7	2.1
First-Order Total	25	18.45	14.10	21.30	20.95	19.35	14.40	19.50
II. SECOND-ORDER PROPERTIES								
A Weight								
1. Installed hardware and heat rejection	7	6.3	5.6	4.9	3.9	4.2	4.2	3.9
2. Resupply	8	2.4	7.2	6.4	6.4	6.4	7.2	7.2
Subtotal	15	8.7	12.8	11.3	10.3	10.6	11.4	11.1
B Power								
1. Peak	6	4.8	1.2	5.1	5.4	5.4	3.6	3.0
2. Average	12	10.8	2.4	10.2	10.8	10.8	7.2	6.0
Subtotal	18	15.6	3.6	15.3	16.2	16.2	10.8	9.0
C Volume								
2	2	1.2	1.6	1.6	1.2	1.6	1.6	1.2
D Reliability								
1. Repairability	5	2.5	4.0	3.5	3.5	3.5	3.5	2.5
2. Simplicity								
a. Controls	4	2.0	2.8	1.6	3.2	2.8	2.8	2.0
b. Basic Functions	3	1.2	2.1	1.8	2.4	1.8	2.1	1.8
3. Independence of failures	4	2.0	2.8	3.2	2.8	2.8	2.8	2.8
4. Process controllability	4	2.4	2.8	2.0	2.8	2.4	2.8	2.4
Subtotal	20	10.1	14.5	12.1	14.7	13.3	14.0	11.5
E Maintainability								
1. Ease of service	1	0.6	0.8	0.8	0.7	0.7	0.7	0.6
2. Frequency of service	1	0.6	0.7	0.5	0.6	0.6	0.7	0.6
3. Manhour demands	2	1.0	1.6	1.2	1.2	1.0	1.6	1.4
4. Error potential	3	1.2	2.1	1.2	1.8	2.1	2.1	2.1
5. Crew exposure to injury or illness	3	1.8	2.1	2.4	2.1	2.1	2.4	2.1
Subtotal	10	5.2	7.3	6.1	6.4	6.5	7.5	6.8
F Safety (Hazard Avoidance)								
1. Fire	2	1.4	1.2	1.4	1.6	1.6	1.4	1.4
2. Explosion	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9
3. Toxicity	2	1.2	1.6	1.2	1.2	1.2	1.6	1.2
4. Contamination buildup	3	1.8	2.1	2.1	2.4	2.1	2.1	2.1
5. Burn or shock	2	1.6	1.0	1.2	1.4	1.4	1.2	1.4
Subtotal	10	6.9	6.8	6.8	7.5	7.2	7.2	7.0
Second-Order Total	75	47.70	46.60	53.20	55.30	55.40	52.50	46.60
Grand Totals*	100	66.15	60.70	74.50	77.25	74.75	66.90	66.10

* Total of first- and second-order properties.

Table 3.3-IX. LSS Rating of Water Recovery/Wash/Processing Systems

TRADEOFF PARAMETER	RELATIVE	RELATIVE RATING							
	SENSITIVITY	ELECTRO- LYSIS	ELECTRICAL VACUUM DISTILLATION PYROLYSIS	VAPOR COMPRESSION ADSORPTION	W/ AIR EVAPORATION	W/ VACUUM DISTILLATION ADSORPTION	W/ VACUUM DISTILLATION PYROLYSIS (STATIC)	W/ VACUUM DISTILLATION PYROLYSIS (DYNAMIC)	MULTI- FILTRATION
	(S _R) OF PARAMETER (H ₂ O RECOVERY)								
I. FIRST-ORDER PROPERTIES									
A Confidence (Degree of development and performance margins)	25	17.45	11.60	21.2	20.1	18.0	11.60	18.20	21.90
B Contribution to advance- ment of the state of the art	0	0	0	0	0	0	0	0	0
First-Order Total	25	17.5	11.60	21.2	20.1	18.0	11.60	18.20	21.90
II. SECOND-ORDER PROPERTIES									
A Weight									
1. Installed hardware and heat rejection	7	6.65	5.6	5.25	4.2	4.9	5.25	3.5	6.65
2. Resupply	10	6.50	8.5	9.5	9.5	8.5	8.5	8.5	1.00
Subtotal	17	13.15	14.1	14.75	13.7	13.4	13.75	12.0	10.65
B Power									
1. Peak	6	5.4	1.2	5.1	5.4	5.4	3.6	3.0	5.7
2. Average	13	12.3	2.6	11.0	11.7	11.7	7.8	6.5	12.3
Subtotal	19	17.7	3.8	16.1	17.1	17.1	11.4	9.5	18.0
C Volume	2	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.6
D Reliability									
1. Repairability	3	1.2	2.1	1.8	1.8	1.8	1.8	1.2	2.7
2. Simplicity									
a. Controls	5	2.5	3.0	2.0	3.5	3.0	3.0	2.5	1.25
b. Basic Functions	4	1.6	2.8	2.0	2.8	2.4	2.4	2.0	4.5
3. Independence of failures	4	2.0	2.8	3.2	2.8	2.8	2.8	2.8	2.8
4. Process controllability	4	2.4	2.8	2.0	3.2	2.4	2.8	2.4	1.6
Subtotal	20	9.7	13.5	11.0	14.1	12.4	12.8	10.9	15.85
E Maintainability									
1. Ease of service	2	1.2	1.4	1.4	1.4	1.2	1.2	1.2	1.6
2. Frequency of service	2	1.4	1.4	1.0	1.2	1.2	1.4	1.2	1.4
3. Manhour demands	1	0.7	0.8	0.6	0.6	0.5	0.8	0.7	0.8
4. Error potential	2	1.0	1.4	0.8	1.6	1.4	1.4	1.4	1.8
5. Crew exposure to injury or illness	3	2.1	2.1	2.4	2.1	2.1	2.4	2.1	2.7
Subtotal	10	6.4	7.1	6.2	6.9	6.4	7.2	6.6	8.3
F Safety (Hazard avoidance)									
1. Fire	2	1.4	1.2	1.4	1.6	1.6	1.4	1.4	1.8
2. Explosion	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
3. Toxicity	1	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.8
4. Contamination buildup	1	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7
5. Burn or shock	2	1.6	1.0	1.2	1.4	1.4	1.2	1.4	1.8
Subtotal	7	5.3	4.6	5.0	5.4	5.3	5.0	5.1	6.0
Second-Order Totals	75	53.85	44.70	54.65	58.80	56.20	51.75	45.30	60.40
Grand Totals*	100	71.35	56.30	75.85	78.90	74.20	63.35	63.50	82.30

* Total of first- and second-order properties.

Table 3.3-X. LSS Ratings of Water Recovery/Humidity-Condensate/Processing Systems

TRADEOFF PARAMETER	RELATIVE SENSITIVITY (S _R) OF PARAMETER (H ₂ O RECOVERY)	RELATIVE RATING							
		ELECTRO- DIALYSIS	ELECTRICAL VACUUM DISTILLATION PYROLYSIS	VAPOR ADSORPTION COMPRESSION	WH AIR EVAPORATION	WH VACUUM DISTILLATION ADSORPTION	WH VACUUM DISTILLATION PYROLYSIS (STATIC)	WH VACUUM DISTILLATION PYROLYSIS (DYNAMIC)	MULTI- FILTRATION
I. FIRST-ORDER PROPERTIES									
A Confidence (Degree of development and performance margins)	22	16.25	10.2	19.6	18.35	16.40	10.2	16.5	20.45
B Contribution to advance- ment of the state of the art	0	0	0	0	0	0	0	0	0
First-Order Total	22	16.25	10.2	19.6	18.35	16.40	10.2	16.5	20.45
II. SECOND-ORDER PROPERTIES									
A Weight									
1. Installed hardware and heat rejection	7	6.3	4.6	4.6	3.5	3.5	4.2	2.1	6.65
2. Resupply	10	8.0	7.0	9.0	9.0	7.0	6.0	7.0	7.0
Subtotal	17	14.3	11.6	13.6	12.5	10.5	10.20	9.1	13.65
B Power									
1. Peak	6	5.4	0	3.6	3.9	3.9	1.8	0.6	5.7
2. Average	15	14.25	0	9.0	9.8	9.8	4.5	1.5	14.25
Subtotal	21	19.65	0	12.6	13.7	13.7	6.3	2.1	19.95
C Volume	2	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.8
D Reliability									
1. Repairability	2	0.8	1.4	1.2	1.2	1.2	1.2	0.8	1.8
2. Simplicity									
a. Controls	6	3.0	3.6	2.4	4.2	3.6	3.6	3.0	5.1
b. Basic functions	4	1.6	2.8	2.0	2.8	2.4	2.4	2.0	3.6
3. Independence of failures	4	2.0	2.8	3.2	2.8	2.8	2.8	2.8	2.8
4. Process controllability	4	2.4	2.8	2.0	3.2	2.4	2.8	2.4	1.6
Subtotal	20	9.8	13.4	10.8	14.2	12.4	12.8	11.0	14.9
E Maintainability									
1. Ease of service	3	1.8	2.1	2.1	2.1	1.8	1.8	1.8	2.4
2. Frequency of service	2	1.4	1.4	1.0	1.2	1.2	1.4	1.2	1.4
3. Manhour demands	1	0.7	0.8	0.6	0.6	0.5	0.8	0.7	0.8
4. Error potential	1	0.5	0.7	0.4	0.8	0.7	0.7	0.7	0.9
5. Crew exposure to injury or illness	3	2.1	2.1	2.4	2.1	2.1	2.4	2.1	2.7
Subtotal	10	6.5	7.1	6.5	6.8	6.3	7.1	6.5	8.2
F Safety (Hazard avoidance)									
1. Fire	2	1.4	1.2	1.4	1.6	1.6	1.4	1.4	1.8
2. Explosion	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
3. Toxicity	1	0.7	0.9	0.7	0.7	0.7	0.8	0.7	0.8
4. Contamination buildup	2	1.4	1.6	1.6	1.6	1.4	1.4	1.4	1.4
5. Burn or shock	2	1.6	1.0	1.2	1.4	1.4	1.2	1.4	1.8
Subtotal	8	6.0	5.6	5.8	6.2	6.0	5.7	5.8	6.7
Second-Order Totals	78	57.85	39.30	50.9	55.00	50.50	49.70	36.70	65.20
Grand Totals*	100	74.10	49.50	70.5	73.35	66.90	53.90	52.20	85.65

* Total of first- and second-order properties.

Independence of Failures. Absence of chain reactions, as when a system is made inoperable by one failing member.

Process Controllability. The degree of adaptability of the system to differences in inputs, throughputs, and component effectiveness.

Error Potential. Degree to which a maintenance error can inflict system damage. For example, inadvertent act "A" produces a flow loss whose only consequence is a function loss, whereas act "B" dumps high pressure into a low-pressure container.

3.3.1.5 Subsystem Arrangement. The most competitive techniques were air evaporation (waste heat) for urine and multifiltration for wash water and condensate. Additional analysis was required to determine the actual arrangement of the final subsystem and whether or not it should employ both techniques. Factors influencing the selection of an integrated system were (1) reliability (probability of failure, repair capability, alternate mode margins, crew safety); (2) weight (hardware, waste heat, heat rejection, spares); (3) power; and (4) maintainability.

The reliability of each system to provide water recovery in its operational environment was evaluated. Reliability modes selected reflected degrees of operational capability and repair capability and tolerances to various processing rates. In general, the LSS crew safety model was employed.

Several combinations of configurations were studied. The final selection was based on an evaluation of six configurations of waste heat air evaporation units and multifiltration units, each operating as an integrated system with two levels of output. The letter designations of the six configurations are shown in Table 3.3-XI.

The two levels of output included in this study are discussed below.

- a. No. 1 -- Minimum Continuous Level. It was considered that the operational crew could continue to operate without calling for emergency resupply under the following conditions:
 1. Surviving subsystems operating 25 percent longer per processing period.
 2. Water allocated for washing reduced by approximately 50 percent.
 3. No reduction in Bosch reactor water makeup.
 4. Water allocated for drinking and food hydration is normal.
 5. Water allocated for washing is potable.
- b. No. 2 -- Design Continuous Level. At this level, the recovery system is operating at or above specified steady-state rates without unscheduled interruption.

Table 3.3-XI. Subsystem Composition and Sizing

DESIGNATION	COMPOSITION
A	Three air evaporation units, each sized to process either urine, wash water, or condensate.
B	Two air evaporation units, each sized to handle urine, and one multifiltration unit sized to handle condensate flow and wash water contaminants.
C	One air evaporation unit sized for urine and two multifiltration units, each sized for condensate flow and wash water contaminants.
D	One air evaporation unit sized for urine and condensate flow (simultaneously)* and one multi-filtration unit sized for wash water.
E	Two air evaporation units, each sized to process urine and condensate flow simultaneously.
F	One air evaporation unit sized to process urine, wash water, and condensate flows simultaneously.

*In order to establish the normal design flow rates for the units, the sizings are related to the specific waste waters being processed. The actual water recovery function can be performed in separate batch processes. A single recovery unit is referred to as a subsystem in this analysis.

In addition to the two continuous operating levels, an emergency level was considered. An emergency exists if, after subsystem failure, the remaining subsystem cannot meet the minimum continuous requirement. The maximum emergency period was defined as 17 days (maximum resupply time).

The 240 pounds of emergency water supply plus the capacity to recover condensate will provide for 17 days of drinking water. All configurations that have three subsystems have the inherent capability to meet the emergency condition without additional equipment. (See Table 3.3-XII.)

To provide this capability for configurations D, E, and F, an on-line (but not normally operating) multifiltration unit weight of 5.3 pounds was provided. This weight was included in the weights shown in Table 3.3-XIII. Compared with a complete supply of potable water for 17 days (510 pounds) the 5.3-pound multifiltration unit allows a saving of approximately 270 pounds in emergency potable water stores.

Table 3.3-XII. Minimum Continuous Level Capacity

<u>Configuration A</u>	<u>20-HR CAPACITY</u>	<u>NOMINAL 16-HR CAPACITY</u>
Evaporation Unit	24.50	19.6
Evaporation Unit	24.50	19.6
Evaporation Unit	Failed	19.6
	<u>49.00</u>	<u>58.8</u>
Urine & Condensate Process Requirements	-32.80	(27% over
	<u>16.20</u>	capacity)
Bosch Makeup	- 1.32	
Available for Processing Wash Water	<u>14.88</u>	
 <u>Configuration B</u>		
Evaporation Unit	16.50	13.2
Evaporation Unit	Failed	13.2
Multifilter	24.50	19.6
	<u>41.00</u>	<u>46.0</u>
Urine & Condensate Process Requirements	-32.80	(0% over
	<u>8.20</u>	capacity)
Bosch Makeup	- 1.32	
Available for Processing Wash Water	<u>6.88</u>	
 <u>Configuration C</u>		
Evaporation Unit	16.50	13.2
Multifilter	Failed	19.6
Multifilter	24.50	19.6
	<u>41.00</u>	<u>52.4</u>
Urine & Condensate Process Requirements	-32.80	(14% over
	<u>8.20</u>	capacity)
Bosch Makeup	- 1.32	
Available for Processing Wash Water	<u>6.88</u>	

Table 3.3-XII. Minimum Continuous Level Capacity, Contd

<u>Configuration D</u>	<u>20-HR CAPACITY</u>	<u>NOMINAL 16-HR CAPACITY</u>
Evaporation Unit	41.00	32.8
Multifilter	Failed	13.2
	41.00	46.0
Urine & Condensate Process Requirements	-32.80	(0% over
	8.20	capacity)
Bosch Makeup	- 1.32	
Available for Processing Wash Water	6.88	
<u>Configuration E</u>		
Evaporation Unit	41.00	32.80
Evaporation Unit	Failed	32.80
	41.00	65.60
Urine & Condensate Process Requirements	-32.80	(43% over
	8.20	capacity)
Bosch Makeup	- 1.32	
Available for Processing Wash Water	6.88	
<u>Configuration F</u>		
Evaporation Unit	57.50	46.00
Minimum Continuous Level not Applicable		(0% over
		capacity)

In general, the reliability values employed throughout the study were derived from the overall LSS reliability apportionment reflected in specifications and from analysis of Convair space launch operations at ETR. Calculations were made on the basis of expected values for the initial 90-day and one-year operational periods. The values were considered to be pessimistic, as only minimal increases in sub-system reliability were allotted from prototype to flight deployment. In addition, it was assumed that the initial 90-day period of the one-year mission is the most severe and that ultimate reliability will not be achieved in the initial year.

Values for mean time between failures are shown in Table 3.3-XIV.

Table 3.3-XIII. Total Water Reclamation System Weights and Power

DESIGNATION	WEIGHT (lb)*					POWER (watts)
	HEAT REJECTION**				TOTAL (1 year)	
	HARDWARE	PENALTY	EXPENDABLES	SPARES		
A 3 Evaporation Units	93.3	94.8	152.0	138.0	478	174
B 2 Evaporation Units	51.4	53.8	148.0	104.0	357	78
1 Filter	6.0	0.3	60.2	37.2	104	10
Subtotal	57.4	54.1	208.2	141.2	461	88
C 1 Evaporation Units	25.7	26.9	134.0	77.0	264	39
2 Filters	12.0	0.6	164.2	51.0	228	20
Subtotal	37.7	27.5	298.2	128.0	492	59
D 1 Evaporation Units	42.1	66.6	148.0	119.0	376	97
1 Filter	6.0	0.3	124.0	37.2	167	10
1 Standby Filter	3.3		2.0		5	
Subtotal	51.4	66.9	274.0	156.2	548	107
E 2 Evaporation Units	84.2	95.5	152.0	150.0	482	194
1 Standby Filter	3.3		2.0		5	
Subtotal	87.5	95.5	154.0	150.0	487	194
F 1 Evaporation Units	53.2	93.5	152.0	148.0	447	136
1 Standby Filter	3.3		2.0		5	
Subtotal	56.5	93.5	154.0	148.0	452	136

* Power penalty is not included in weight summary.

** Sum of the heat rejection and process heat penalties.

Table 3.3-XIV. Mean Time Between Failures (MTBF)

		90-DAY MISSION PHASE (hours)				
		1st	2nd	3rd	4th	Average
Phase Change	Urine	530	800	1100	800	810
	Condensate	750	1140	1960	1140	1250
Single Phase	Condensate	2000	3000	4000	3000	3000
	Wash	1500	2250	3000	2250	2250

The initial study was performed for three spares levels; 100, 90 and 80 percent. Actual numbers of spares required for these levels for various component MTBF's are shown in Figure 3.3-13. The 80-percent values were used in the subsystem weights calculations.

Reliability was considered to be the probability of successful repair for each of the failures estimated to accompany the given system. The probability that the repair will be successfully completed in the allowable time was taken as both 95 percent and 90 percent. The reason for so doing was to search out differences that might accompany various system configurations and eventually various subsystem designs for chosen configurations. The 95-percent value was considered appropriate for the trade-off and is based on judgmental upgrading of repair task capabilities demonstrated by Convair space launch crews at ETR.

The probability of maintaining at least each of the two processing rates, minimum and design, for the initial 90-day and one-year operational periods was developed. The probabilities for each configuration as a function of mission time completed or contemplated are plotted in Figure 3.3-14.

The weight of the six configurations reflects the requirement for minimum continuous water recovery. The weights for spares were calculated. In Figure 3.3-15, bars 1 and 2 illustrate the significance of spares weights for multiple-unit systems when units are identical. For example, bar graph 1 indicates that spares weight for a single-unit system was calculated as 70 percent of basic unit weight, while a three-unit system adds only 35 percent for the additional two units.

A configuration rating method similar to that employed in the evaluation of the individual water recovery subsystems was employed. The five parameters considered significant in the evaluation of the integrated water recovery system were assigned relative weighting factors. The individual configurations were then assigned merit values between zero and 10. (See Figure 3.3-16.) The higher the merit value, the more acceptable is a given configuration for the factor being considered. The

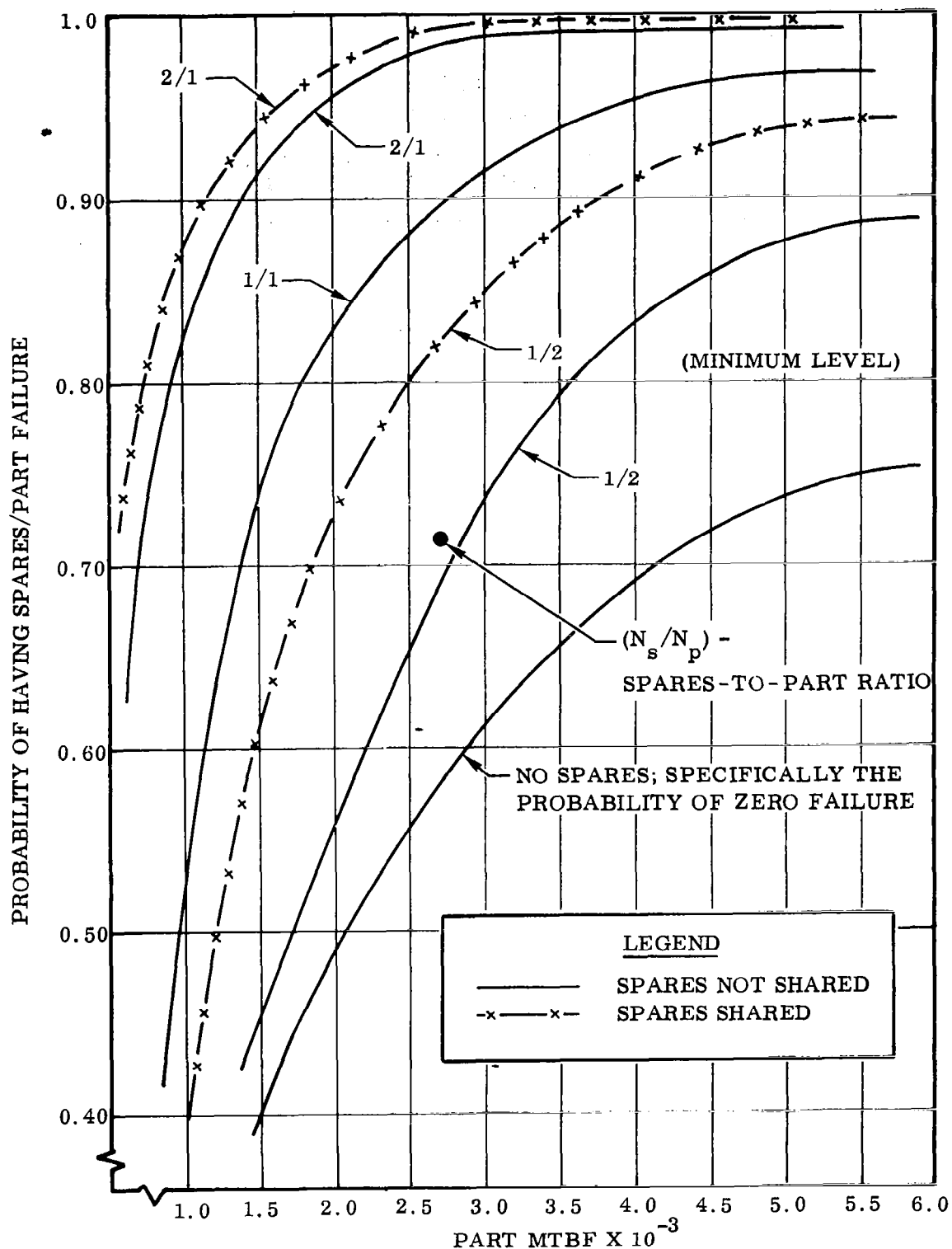


Figure 3.3-13. Probability of Adequate Spares for Several Spares Levels vs. Parts MTBF

NOTES:

1. CURVES BASED ON AVERAGE VALUES OF MTBF
2. CONFIGURATION DESIGNATIONS AS IDENTIFIED ON RATING CHART

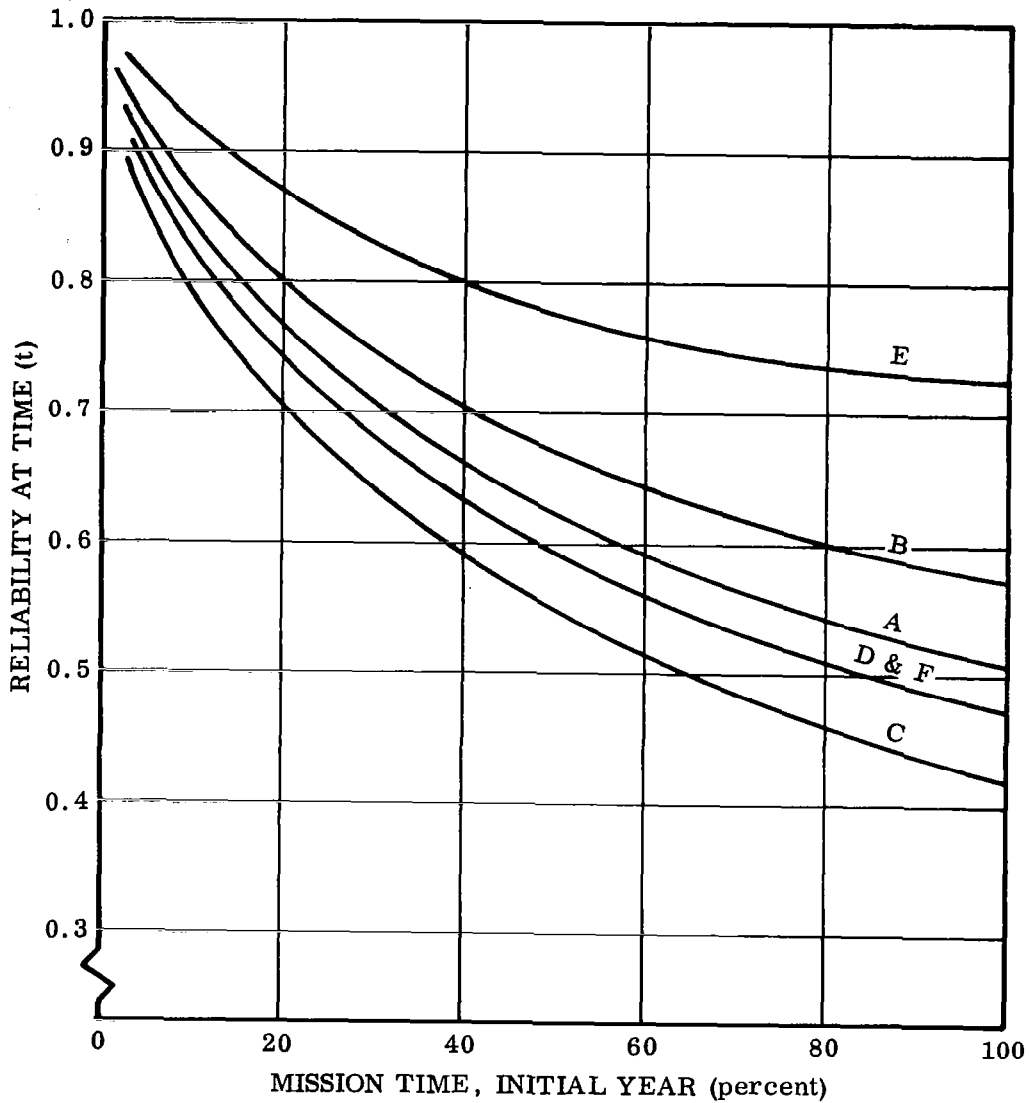
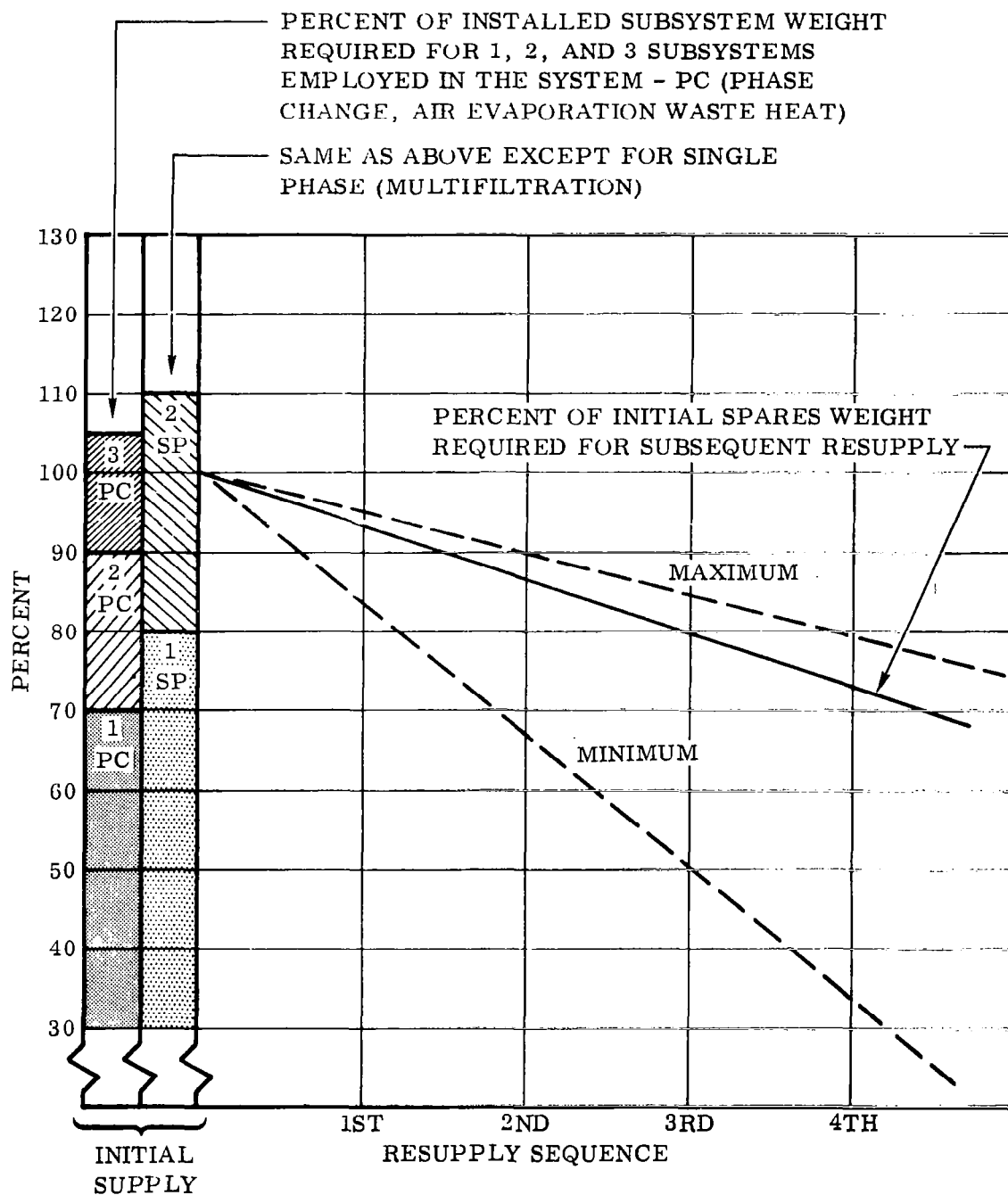


Figure 3.3-14. Mission Time vs. Probability of Maintaining at Least Minimum Water Recovery Requirements During Initial Year of Operation



NOTE

VALUES BASED ON SURVEY OF ACTUAL DESIGNS APPORTIONED
TO THE RELIABILITY VALUES EMPLOYED IN THE SYSTEM
TRADEOFF STUDIES (MAXIMUM VALUES)

Figure 3.3-15. Weight Calculations, System Spares

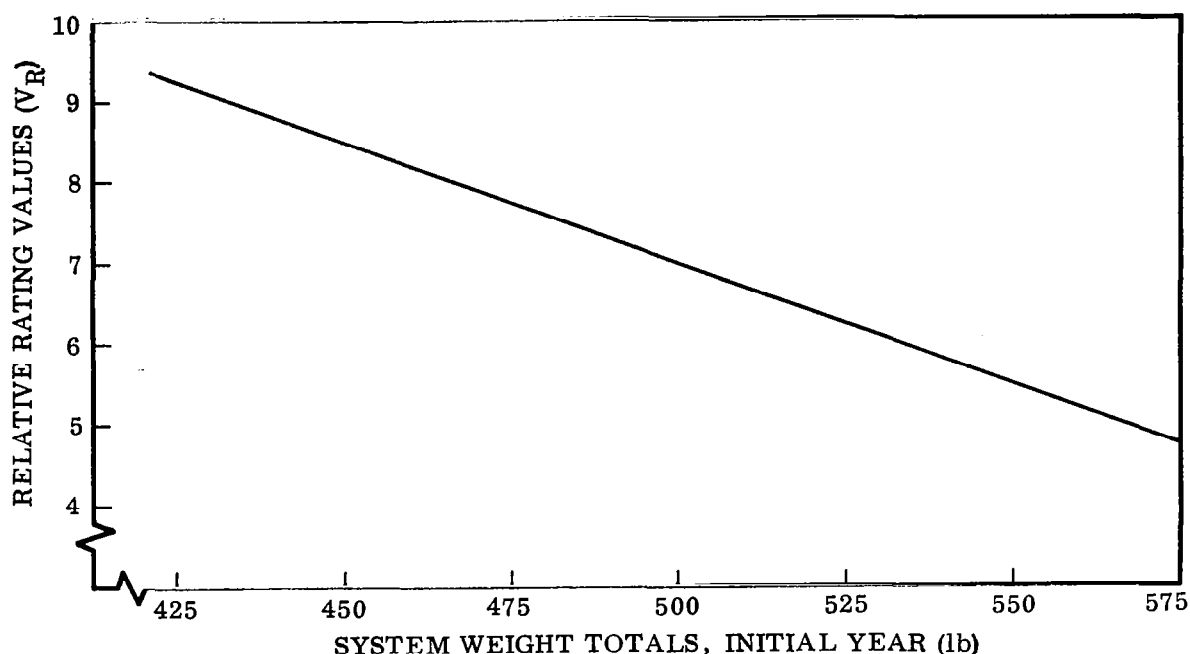


Figure 3.3-16. System Merit Values vs. System Weight

reliability merit values were established from actual reliability numbers; for example, a merit value of 7.2 for reliability corresponds to a reliability number of 0.72. The merit values for system weight were obtained from the characteristic plot of merit values versus system weight. The final rating of the configurations was based upon the summation of the individual scores of all the five parameters considered in the evaluation. (See Table 3.3-XV.)

3.3.2 TECHNIQUES SELECTED. It was recommended that two identical waste heat air evaporation recovery units (Configuration E), each sized to process 32.8 pounds of water in a 16-hour period be used, because this scheme:

- a. Has the greatest probability of maintaining an acceptable level of water supply without causing an abort.
- b. Reduces the total number of operating components and simplifies the operational procedures required of the crew.
- c. Permits operating for fewer than the nominal 16 hours per day under normal conditions, thereby further increasing total reliability and permitting potable analysis and reprocessing in a shorter time cycle.

Table 3.3-XV. Integrated Water Reclamation System Rating Chart

CONFIGURATION PARAMETER	WEIGHTING FACTOR	(SCORE) = X (MERIT VALUE 0 TO 10) = Y	A	B	C	D	E	F
			SS(a) = PC	SS(a) = PC	SS(a) = PC	SS(a) = PC	SS(a) = PC	SS(a) = PC
			SS(b) = PC	SS(b) = PC	SS(b) = SP	SS(b) = SP	SS(b) = PC	SS(b) = PC
			SS(c) = PC	SS(c) = SP	SS(c) = SP			
Minimum continuous- level reliability	48	X	24.5	27.8	20.2	23.0	55.0	23.0*
		Y	5.1	5.8	4.2	4.8	7.3	4.8
Design continuous- level reliability	10	X	1.3	1.6	2.2	3.3	2.7	4.8*
		Y	1.3	1.6	2.2	3.3	2.7	4.8
Maintainability	8	X	4.4	5.0	5.8	6.8	6.4	7.2
		Y	5.5	6.3	7.3	8.5	8.0	9.0
Weight (includes spares and expend- ables but excludes weight for power)	16	X	12.2	13.1	11.7	8.8	11.8	13.4
		Y	7.6	8.2	7.3	5.5	7.4	8.4
Power	18	X	11.5	14.4	15.3	13.8	10.8	12.6
		Y	6.4	8.0	8.5	7.7	6.0	7.0
TOTAL	100		53.9	61.9	55.2	55.7	66.7	61.0

* The division of reliability into design and minimum continuous level is not appropriate for the single unit subsystem (F); however, it is an important evaluation factor for the other five multi-unit water-recovery subsystems. For example, if the reliability is considered only for the minimum continuous recovery level and the weighting factor used is 58, then the following total ratings for the configurations are obtained: A = 59.3; B = 65.6; C = 54.3; D = 56.9; E = 72.6; F = 62.6.

- d. Ranks the highest on the rating chart, which considers reliability, weight, power, and maintainability.

It was also recommended that an on-line (normally not operating) multifiltration unit be installed for emergency use.

3.4 WASTE MANAGEMENT

The waste management subsystem includes the collection, treatment, and disposal of all nonrecoverable solid and liquid wastes and the collection and transport of urine to the water recovery subsystem. Prior system studies had shown that water recovery from feces and other low-water-content complex matter was neither practicable nor necessary. The evaluation of the nonrecoverable waste functions therefore had little or no influence on the evaluation of the urine collection and transport functions and the two were considered somewhat independently. The discussion that follows excludes urine collection and transport unless otherwise indicated.

Waste management techniques that could reasonably be expected to be available for the development program were surveyed and evaluated in terms of the three basic functions of collection and transport, treatment, and disposal.

3.4.1 TECHNIQUES CONSIDERED. As far as feasible, techniques for performing each of the three nonrecoverable waste management functions were considered separately. Techniques were considered in their abstract form rather than as they might exist within existing system designs providing several functions. This approach minimized the possibility of prematurely rejecting a total system design simply because it contained a noncompetitive technique not necessarily inherent to the design.

3.4.1.1 Feces Treatment. Fecal matter requires positive treatment or processing in some form to permit either its temporary storage in a spacecraft or its permanent storage in space. Although the complexity of the treatment function is affected by the storage techniques employed, certain techniques could be determined unacceptable for the LSS and most could be roughly compared and quantitatively rated. The seven basic techniques investigated are summarized in Table 3.4-I.

3.4.1.2 Feces Collection and Transport. Feces collection and transport is the receipt of feces directly from the crew member anal area and delivery under zero-g to the treatment function. The principal problems associated with collection and transport are:

- a. Provision for zero-g operation.
- b. Psychological aspects for long-time use.
- c. Hygienic aspects.

Table 3.4-I. Feces Treatment Techniques

TECHNIQUE	PROCESS	EQUIPMENT REQUIREMENTS (1)	APPARENT SAFETY (2)	EXPENDABLE REQUIREMENTS (3)	WEIGHT/ POWER/ VOLUME (4)	PROCESS RESIDUALS AND REDUCTION OF OTHER WASTES (5)	DEGREE OF PASSIVATION (6)	STATE OF DEVELOPMENT (7)	DEGREE* OF ACCEPTABILITY
Biological	Controlled bacteriological decomposition and reduction of fecal matter, not unlike conventional septic tank.	Reusable vats or tanks. Transfer pump and valves. Phase separation controls. Process instrumentation. Heat sink.	Questionable	Low (time requirement is high)	High	Very high (none)	Low (incomplete process)	Very low	Unacceptable 1, 2, 4, ③, ⑥
Freeze Drying	Water (urine) added to feces; resulting slurry subjected to vacuum.	Rotating machinery, valves, vacuum lines, cleaning equipment.	Good	Very high (water)	Average to low	Low (negligible)	High	Prototype	Unacceptable ③
Freezing	Feces in containers kept in freezer.	Bulk storage freezer, electrical power, space radiator, etc.	Fair	Low	Very high	Maximum (none)	Temporary	High	Unacceptable ①, ⑥
Thermal Decomposition	Vaporization of solids at extremely high temperatures; vapors discharged to space.	Pyrolysis chamber(s). Space vacuum circuit with valving.	Fair to good	Very low (same cabin air loss)	Power very high	Negligible (significant)	Complete	Experimental models	High for long missions ③, ⑤ Poor for short missions ④
Incineration	Solids oven dried and then ignited in an O ₂ atmosphere; gases vented to space.	Drying oven(s) and/or incinerator. Heating elements. Gas vent circuit to vacuum.	Fair	Fairly high (oxygen)	High	Negligible (very significant)	Complete	Prototypes	Fair to marginal 2, ③, 6
Chemical	Chemicals physically mixed with feces to passivate and sterilize organic and bacterial matter.	Varies with degree of manual operation. Ranges from merely chemical storage to chemical storage, transport, mixing, and packaging.	Questionable to fair	Low to average	Negligible to average	Maximum (none)	Variable	Experimental models	Marginal ②, ⑥
Heat-Vacuum Drying	Heat added to solids to support vacuum drying.	Vacuum circuit and controls, integrated with thermal drying oven(s).	Good	Low	Low	Low (negligible)	High	Prototype	Good 2 - 7

* Major reasons for acceptability or unacceptability are circled.

- d. Process dependability.
- e. Degree to which the technique complicates and/or increases the magnitude of the treatment and storage function.
- f. Support demands in terms of weight, power, volume, expendables, and crew time.

Table 3.4-II provides a partial description of the evaluation.

3.4.1.3 Feces Disposal. Disposal of nonrecoverable wastes fell into two categories: temporary storage aboard the spacecraft, with removal at resupply; and discarding to space (venting and/or jettisoning). Except for the venting of bacteria-free gases and vapors, disposal to space was not considered appropriate, at least to the time period of the program. All disposal techniques considered competitive were to provide temporary on-board storage. The storage containers studied fell into three categories: sealed pressure vessel, ambient vented, and controlled environment. The treatment techniques considered influenced the selection of storage methods. Controlled-environment storage, essentially freeze storage, was ruled out because of its high weight and power requirements and the safety hazard associated with the loss of refrigerant capability. Thus only passive storage techniques were considered in detail.

3.4.2 WASTE MANAGEMENT EQUIPMENT. Nine equipment combinations were compared and ranked against the specified selection parameters. Table 3.4-III summarizes the comparison. Figure 3.4-1, a weight comparison, shows one step in the evaluation.

3.4.3 URINE COLLECTION AND TRANSPORT. Three techniques for the collection and transport of urine under zero-g were sufficiently developed to warrant detailed study. One approach employed a receiving cone connected to the inlet of a centrifugal liquid-gas separator by a flexible tube; the zero-g capability was supplied by ducted air drawn through the receiving cone. The liquid-gas separator provided both the separation function and the pumping action for the urine transport. A second technique consisted of a rubber bladder that collected urine directly from the crewmember. The urine is then manually discharged into the transport system. A third approach employed a centrifugal impeller-type pump with an inlet configured to accept the urine stream directly from the crewman. The pumping action provided both liquid-gas separation and transport to the water management collection circuit. Several impeller drives were available, including a spring-wound device. All three techniques were considered competitive.

3.4.4 SELECTED TECHNIQUES. The selected techniques provided feces collection by a ducted air stream passing through a semipermeable collection bag supported in an adjustable frame and located below a conventional toilet seat. Feces and other water-bearing solids are treated by vacuum drying supported by the addition of heat. Storage is provided by ambient vented, sealable containers. The urine collection and transport functions combine two of the three techniques discussed -- the

Table 3.4-II. Feces Collection and Transport Techniques

TECHNIQUES	PROCESS	EQUIPMENT REQUIREMENTS	APPARENT SAFETY	EXPENDABLE REQUIREMENTS	WEIGHT/ POWER/ VOLUME	PSYCHOLOGICAL ACCEPTANCE	BURDEN PLACED ON TREATMENT/ STORAGE	STATE OF DEVELOPMENT	DEGREE OF ACCEPTABILITY
A. Air Flow to a Container	1. Air flow directs feces into a single-use, non-recoverable bag; transport to treatment is manual.	Blower, ducting, bag holder, stool filter(s), valving	Fair to good	High	Average	Good	Low	Prototype	High
	2. Feces directed to multiple-use, nonrecoverable containers of rigid construction. No transport to treatment required.	Blower, ducting, replaceable containers with sealing covers, filter(s), valving.	Fair to good	Low	Average to high	Questionable	Low	Prototype	Fair
	3. Air flow directs feces into container inlet, where flush water and blender/pump transport slurry to a flush water recovery evaporator. Transport to treatment is mechanical.	Stool, blender/pump, evaporator, condenser, flush pump, ducting and tubing, valving.	Good to excellent	Very low	Very high	Excellent	Negligible	Prototype	Fair
	4. Same as Process 2, except container is single-use.	Same as Process 2	Good to excellent	Low	Average to low	Good	High	Experimental model	Fair
B. Manual Manipulation	Plastic collection bag is attached around buttocks at the time of defecation; feces are manually directed into bag.	Reusable harness and/or collection bags.	High	High	Minimal	Fair	High	In operational mission	Fair

Table 3.4-III. Ranking Chart, Waste Management Equipment Combinations

EQUIPMENT COMBINATION (COLLECTION-TREATMENT-STORAGE)	DEVELOPMENT CONFIDENCE	OFF-DESIGN CAPABILITY	CONTRIBUTION TO DEVELOPMENT	RELI- ABILITY	MAINTAIN- ABILITY	PSYCHOLOGICAL ACCEPTABILITY	SAFETY	WEIGHT	TOTAL SCORE	RANK
1. Air flow to bag; manual chemical; multiple-use sealed cans.	3	5	6	3	2	7	3	3	32	3rd
2. Air flow to bag; heat/vacuum dry; ambient cabinet.	4	6	5	4	4	3	1	2	29	1st
3. Air flow; water flush and pump; ambient cabinet.	6	1	2	8	9	1	6	5	38	5th
4. Manual; manual chemical; multiple- use sealed cans.	1	7	8	1	1	9	5	1	31	2nd
5. Air flow to multiuse tank; chemical; sealed collector.	2	3	7	2	3	8	4	4	33	4th
6. Air flow to bag; freezing; freezer.	5	4	9	6	7	2	5	9	47	7th
7. Air flow to bag; incineration; ambient cabinet.	9	9	3	6	5	4	7	8	51	9th
8. Air flow to bag; thermal decompres- sion; ambient cabinet.	8	8	4	5	6	5	2	6	44	6th
9. Air flow to single-use can; chemical; sealed collector.	7	2	1	7	8	6	6	7	44	6th

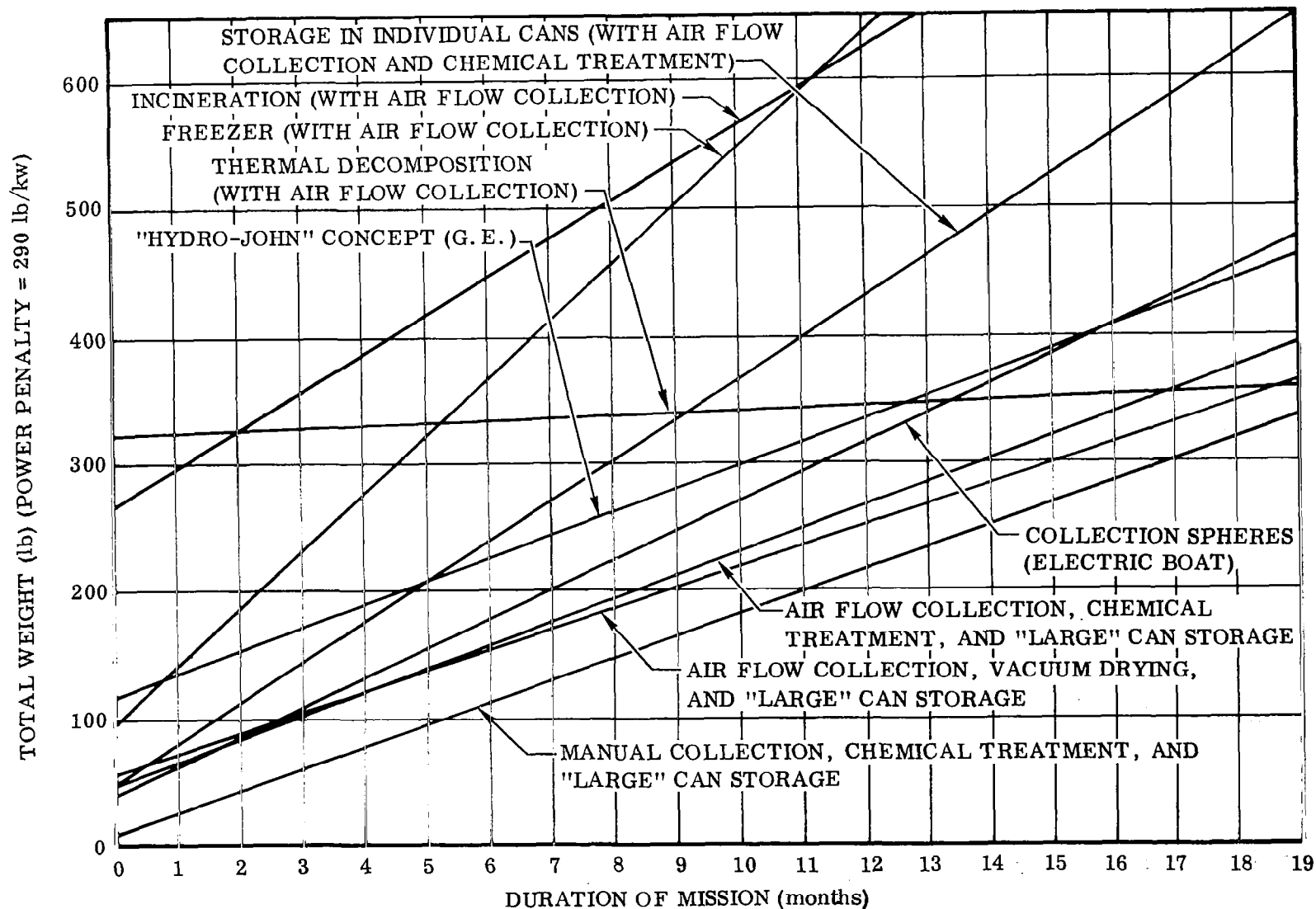


Figure 3.4-1. Comparison of Waste Management Techniques

cone-airflow-liquid/gas separator to perform in the normal mode, with the bladder device acting as a backup. The direct-injection impeller device was considered more likely to cause sanitation and handling problems than the more rigidly installed dynamic separator.

3.5 PERSONAL HYGIENE

A broad survey was made of development and study programs involving personal hygiene in manned space systems. The significant physical and psychological problems associated with the development of body cleansing techniques and a sparsity of multidiscipline studies have seriously limited the state of the art. However, several generalized approaches were sufficiently developed and documented to provide a basis for comparison.

3.5.1 TECHNIQUES CONSIDERED. Techniques for body cleansing, dental cleansing, and grooming were evaluated under the following guidelines.

- a. Water quantity requirements should be adjusted to the capabilities of the water recovery subsystem.
- b. Equipment and procedure complexity should be reduced to an absolute minimum that will support an adequate level of psychological and biological well-being for the crew.
- c. Under highly motivated conditions, crewmen in long confinement have demonstrated that very austere approaches to personal hygiene have been satisfactory.
- d. General analytical guidelines for the overall LSS, as defined by the system specification, should be followed.

3.5.1.1 Body Cleansing. The zero-g environment and restrictions on water quantity were the major determinants in the development of a satisfactory bathing device. Two basic methods appeared feasible. One employed free stream water in a plastic personnel shroud. The other employed various mechanisms for entrapped water (sponge, pads) or other cleansing compounds for use in the open cabin. The use of pretreated wash water was compared with the conventional method of applying cleansing agents directly to body surfaces. Table 3.5-I summarizes the candidate approaches. Further study concerning the requirements for deodorants was considered mandatory.

3.5.1.2 Dental Cleansing. No serious problems were uncovered in the study of dental cleansing, although the disposal techniques for waste cleansing materials to minimize water loss and/or cabin contamination do require study. Tooth cleansers considered included impregnated cloth pads or sponges, conventional and specially configured brushes, and chewing gum containing soluble abrasives and activated charcoal. Included with these techniques were various methods of delivering water and dentrifrice to the teeth and approaches to waste disposal. A study of ingestible dentrifrices was included.

Table 3.5-I. Body Cleansing Techniques

	TECHNIQUES	DESCRIPTION	DEVELOPMENT INFORMATION	DEGREE OF DEVELOPMENT	EVALUATION
			SOURCE		
Free-Stream Bathing	Bath Suit	Loose-fitting suit with free water circulation; soap solution in sponge.	AFSC WPAFB	Experimental model	Zero-g operation not apparent. Water use rather high.
	Bathing Chamber	Plastic chamber or personnel shroud with cleansing action supplied by 1. mittens wetted in cleansing agent and rinsing compound; 2. high-velocity water spray; 3. ultra-sonic energy.	Bjorksten Research Laboratory	Primarily conceptual, with little or no equipment experience	Approach is bulky for 1 and 2; 3 requires study of effects on humans.
Trapped-Water Cleansing	Impregnated Textile Pads	Cleansing pad requires no water; lintless dry cloths for wipe-off.	Whirlpool Corp.	No experimental data available	Requires demonstration prior to selection.
	Water-wetted Sponge	Sponge is wetted with clean water and detergent in a zero-g device	Electric Boat	Experimental data obtained from controlled man-tests.	Low water consumption with proven results.

3.5.1.3 Grooming. The problems associated with grooming are essentially those of minimizing cabin contamination and simplifying the disposal task. For these reasons dry shaving and clipping devices with provisions for particulate collection were the only competitive candidates. Essentially conventional configurations were studied with both electric and spring-wound power sources. Air-stream collection was compared with electrostatic collection of facial and head hair clippings.

Nail clipping posed no problem, especially when accomplished with the aid of the feces collector airstream.

Collection and disposal of miscellaneous solid and liquid body discharges require no more than the conventional tissue wipes, with direct storage or drying prior to storage, depending on the quantity and quality requirements for passivating and/or drying.

3.5.2 TECHNIQUES SELECTED. Sponge bathing with wash water pretreated with benzalkonium chloride (BAC) was selected for bathing. Chemical dry wipes and disposable towels were selected as a supplement.

Conventional tooth brushes and edible dentrifice was selected for dental cleansing. The crewman's zero-g drinking container is employed for the water supply.

A mechanical shaver and safety scissors were selected for grooming.

3.6 FOOD MANAGEMENT

The food management studies principally concerned food-processing techniques, packaging, and menu organization.

3.6.1 NUTRITIONAL REQUIREMENTS. Nutritional requirements designated by the crew model and system specification were 2800 K cal/man-day. A consensus from space nutrition studies conducted by government, educational, and industry sources established a further breakdown as follows.

2800 K cal/man-day

15 percent protein

60 percent carbohydrate

25 percent fat

2 percent crude fiber (by weight prior to rehydration)

<u>Vitamins</u>	<u>mg/man-day</u>
Thiamine	1.6
Riboflavin	1.8
Pyridoxine	4.0
B12	15.0
Alpha Tocopherol	200.0
Ascorbic Acid	200.0
Others per National Research Council standards	

It was noted that additional calcium might be required to combat chronic weightlessness syndrome.

3.6.2 FOOD PROCESSING TECHNIQUES. Several food processing techniques were studied including:

- a. Freeze drying.
- b. Thermal dehydration (natural and synthetic foods).
- c. Freezing.
- d. Water content reduction (concentrates).
- e. Natural state packaged foods for ambient storage.

Methods d and e except for certain specialty items, such as confections and breads, were rejected as impractical from a weight and volume standpoint. Freezing was determined to be competitive only insofar as storage could be integrated with other uses of an onboard freezer (e.g., if increased freezer capacity storage were needed, as for a constant-rate accumulation of scientific and/or biological waste materials).

3.6.2.1 Techniques Selected. Feasible processed foods were found to be restricted to the following.

Freeze dried for precooked foods.

Dehydrated beverages.

Dried fruits and confections.

Hydrated (low-moisture), high-energy-content breads and pasteries.

Frozen desserts as allowable by available freezer space and power.

3.6.3 FOOD FORM AND PACKAGING. Zero-g reconstituting and eating, together with storage and disposal problems, dictated the selection of the single plastic bag providing storage and reconstitution. Items not requiring reconstitution and thus eaten dry strongly favor bite-size packaging in edible film.

Selection of the forms to be used for reconstituted foods required investigation of: natural-form foods, which reconstitute to their natural shape, consistency, color, etc., such as whole peas and chunk meats; and homogeneous-form foods, which reconstitute to a homogeneous slurry. Both types were considered in individually packaged and mixture-packaged forms.

There was much to indicate that a considerable potential existed for the use of homogeneous mixtures. However, it was found that most of the recent space nutrition studies, both experimental and conceptual, had been restricted to the development of food forms and packaging to simulate the idealized home-cooked meal. It was therefore decided to follow this approach.

3.6.4 MENU SELECTION. Menu selections were devised by balancing such factors as:

- a. Inherent natural-state quality-retention of the food item.
- b. Ease of reconstitution.
- c. Nutritional value and composition.
- d. Popularity.
- e. Ingestability.
- f. Digestability.

Conceptual studies of man's nutritional requirements in a zero-g environment and empirical information on aircraft and submarine crew requirements indicated that four equal-energy meals per man-day would be a best initial approach.

3.7 INSTRUMENTATION AND CONTROLS

3.7.1 OPERATIONAL REQUIREMENTS. The LSS test bed is a man-operated system. To provide the greatest probability of successful operation, optimum utilization of man had to be realized. The crew was assumed to be capable of system operation, performance evaluation, and maintenance through visual displays of system variables (temperatures, pressures, flows, etc.). Activity was scheduled to permit crew availability for: periodic inspection and maintenance and intermittent control functions for each subsystem; and quasi-continuous attention to an overall LSS operational status display. (Warning light and accompanying alarm used to initiate crew attention.)

Certain constraints in using man are as follows.

- a. Manual controls must be operable by one man in a flight suit at zero-g.
- b. Crew-manipulated controls must not require constant attention.
- c. Controls must be designed to prevent man-induced failures or inadvertent actuation of emergency modes.
- d. The crew must not be relied upon for safety cutoff control functions.
- e. Informational displays must be provided to meet operational requirements and organized to permit rapid, timely evaluation of system performance.

3.7.2 CRITERIA. A series of project meetings was held in which informal simulations of operational situations were conducted. Crew activity under normal and emergency conditions was studied. General system criteria evolved as follows.

Spacecraft Installation. Digital indications of subsystem operating status and emergency shutdown capability should be summarily displayed at a centrally located status panel. Compound emergencies that might make timely shutdown at the equipment location impossible were considered. Analog readouts and controls should be located on equipment performance panels at the equipment installation. Measured parameters and controls should be selected to permit crew operation, performance evaluation, and maintenance of subsystem.

Ground Monitoring and Control Facility. This facility should provide information and controls available at the on-board status panel, selected items from the equipment performance panel, a mechanism for removing process loop samples from the test bed for laboratory analysis, and facilities for future additional readouts.

3.7.3 FUNCTION. Functions of the instrumentation and control system include: sensing and readout of physical quantities, such as temperature, pressure, flow, and electrical power; the means of controlling certain of these quantities; and alarms to warn of critical malfunctions. The system is physically divided into two subsystems -- spacecraft and ground control.

3.7.3.1 Spacecraft System. The spacecraft system provides:

Simple, reliable controls for stable performance and safe operation of the LSS by the crew. Manual overrides and crew adjustment are incorporated for increased system flexibility and reliability.

Information displays and/or alarms to ensure crew safety, evaluate performance, and permit on-board troubleshooting of the LSS.

Automatic safety cutoffs to prevent self-destruction and fire hazard.

3.7.3.2 Ground Control System. The ground control system provides:

Simple, reliable, external or override controls for unmanned operation.

Information displays and/or alarms to the ground test conductor for evaluation of crew safety and system performance.

A sampling system to permit external laboratory analysis of cabin atmosphere and process loop constituents.

Power distribution and control to the spacecraft simulator.

Auxiliary power receptacles (115 volts, 60 cps) for use of test equipment, tools, etc.

Controls for ground service functions; e.g., spacecraft radiator simulator unit, gas supply vacuum service.

Audible communication under all expected operating conditions between test conductor, spacecraft crew, and chamber operating crew.

3.7.4 CONFIGURATION. The functional and operational system requirements were reviewed to establish the instrumentation and control system configuration. (See Figure 3.7-1.)

A panel mounted integral with each subsystem controls and quantitatively evaluates subsystem performance to permit failure analysis and maintenance. Each panel is designed and fabricated by the subsystem vendor. This permits maximum use of reliable, direct-reading, industrial type instrumentation.

The operating status panel is a centrally located, composite display of all subsystems status and on/off electrical power control. The panel provides an instantaneous display of the LSS status. Each subsystem status is indicated by out-of-tolerance indicator lights for each critical subsystem parameter. (All light indicators are normally off.)

The ground control console provides data display and controls to permit safe manned and unmanned operation of the test bed by the test conductor and ground control team. It consists of the following: display of all subsystems status; electrical power control and analysis; cabin atmosphere pressurization control and leak simulation; gas sampling facility; electronic heat load simulator controls; critical system pressures; critical system temperatures recorded on a multipoint recorder; and status light activity on events recorders to provide a permanent record.

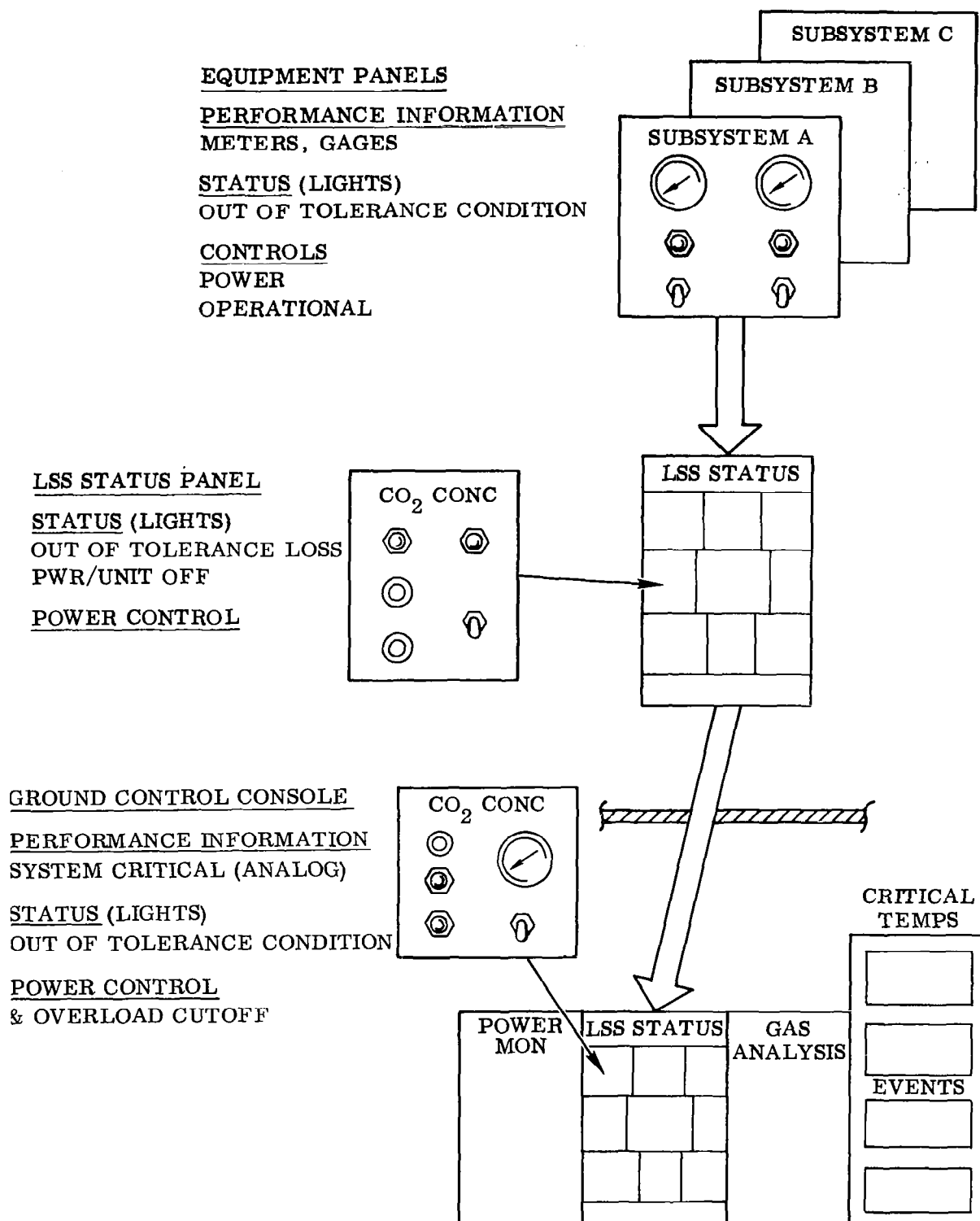


Figure 3.7-1. Instrumentation and Control System Configuration

SECTION 4

SUBSYSTEM SPECIFICATION

The technical requirements for procured equipment were defined and documented by specifications. Certain general requirements were derived from the mission, spacecraft, and crew model criteria and applied equally to all elements of procured equipment. However, the requirements peculiar to the individual subsystems were established in detail only after extensive analysis, evaluation, and coordination with prospective suppliers. General requirements included conditions and assumptions for inspection, maintenance, servicing, instrumentation, and safety provisions. Specific requirements are characterized by identification of the preferred processes, process rates, power, weight, envelope, materials, and methods of fabrication.

4.1 THERMAL CONTROL

The thermal control subsystems and components to be procured to meet performance specifications are listed below.

- a. Fluid cooling and pumping unit (radiator simulator).
- b. Fluid heating and pumping unit (power system simulator).
- c. Coolant fluid heater (electronic equipment simulator).
- d. Air (duct) heater (electronic equipment simulator).
- e. Cabin air heat exchanger.
- f. Cabin air temperature control system.

The remaining components, which constitute the thermal control circuits, were to be selected primarily on the basis of functional capabilities.

4.1.1 FLUID COOLING AND PUMPING UNIT. The fluid cooling and pumping unit shall simulate the space radiator system. The unit shall consist of (1) a refrigeration system capable of cooling 1500 lb/hr of FC-75 from an inlet temperature of 50-150° F to an automatically controlled discharge temperature of $32 \pm 2^\circ$ F; and (2) a pumping system capable of delivering fluid flow rates of 400 - 2500 lb/hr to within 1.5 percent of a manually preselected value and develop a minimum discharge pressure of 65 psig above the inlet pressure at a flow rate of 1500 lb/hr.

Provisions shall be incorporated into the design to prevent damage from fluid expansion, overpressure, and fluid contamination (particulate matter). Automatic controls shall be provided as required to preclude damage to the unit in the event of flow or electrical power interruption or of refrigerant circuit malfunction.

Convair Report No. 64-02013, "Fluid Cooling and Pumping Unit, Life Support System Specification for," dated 26 December 1963, as amended by Revisions A and B, dated 14 March and 1 July 1965 respectively, gives the detailed design specifications.

4.1.2 FLUID HEATING AND PUMPING UNIT. The fluid heating and pumping unit shall simulate the spacecraft dynamic power system. The unit shall consist of (1) an electric heating system capable of heating 300 lb/hr of DC-331 from an inlet temperature of 140-300° F to an automatically controlled discharge temperature of $390 \pm 10^\circ$ F; and (2) a pumping system capable of delivering a manually preselected fluid flow rate of 0-750 lb/hr and develop a minimum discharge pressure of 40 psig above the inlet pressure.

Provisions shall be incorporated into the design to prevent damage from fluid expansion, overpressure, and fluid contamination (particulate matter). Automatic controls shall be provided as required to preclude damage to the unit in the event of flow or electrical power interruption and during start, when the flow must precede heating.

The unit shall also incorporate a device to automatically cut off electrical power any time the fluid temperature reaches 415° F. This control shall be independent of the normal system and shall not be affected by its failure.

Convair Report No. 64-02011, "Fluid Heating and Pumping Unit, Specification for," dated 26 December 1963, as amended by Revisions A and B, dated 8 April and 6 July 1964 respectively, gives detailed design specifications.

4.1.3 COOLANT FLUID HEATER. The coolant fluid heater shall simulate the thermal load imposed upon the coolant circuit by the spacecraft electronic equipment. The unit shall electrically heat fluid (FC-75) entering it at a flow rate of 1000 lb/hr and a temperature and pressure of 32-90° F and 75 psig respectively. The electrical input to the heater shall be adjustable from 0 to 2 kw and shall be automatically maintained at any preselected wattage within this range.

Automatic controls shall be provided as required to preclude damage to the unit in the event of an interruption in fluid flow. A high-temperature warning device that will activate if the fluid discharge temperature from the heater exceeds 150° F shall be provided. A manual reset high temperature cutoff shall also be installed to shut off power when the fluid temperature reaches 170° F.

Convair Report No. 64-02012, "Coolant Fluid Heater, Life Support System Specification for," dated 27 December 1963, as amended by Revision A dated 18 December 1964, gives the detailed design specifications.

4.1.4 AIR (DUCT) HEATER. The air heater shall be located in the duct system upstream of the main cabin air blower and shall simulate the thermal load imposed upon

the air circuit by the ducted spacecraft electronic equipment. The unit shall electrically heat air entering it at a nominal flow rate of 100 cfm at a temperature of 68-85° F and a pressure of 10-14.7 psia. The electrical input to the heater shall be adjustable from 0 to 750 watts and shall be automatically maintained at any preselected wattage within this range.

Automatic controls shall be provided as required to preclude damage to the unit in the event of an interruption in air flow. A high-temperature cutoff shall also be installed to shut off power when the air temperature reaches 170° F or the duct surface temperature reaches 120° F.

4.1.5 CABIN AIR HEAT EXCHANGER. The unit shall be an air-to-liquid heat exchanger capable of cooling and dehumidifying 900 lb/hr of air at a pressure of 10 psia from 106° F (humidity ratio = 0.010 lb/lb/da) to 40° F using a coolant (FC-75) flow rate of 1600 lb/hr at an inlet temperature of 35° F. At these design conditions, the air and coolant static pressure drops shall not exceed 1.0 in. wg, and 12 psig respectively.

The unit shall be oriented for vertical downward air flow and shall release condensate in a uniform pattern across the air discharge fitting.

Convair Report No. 64-02010, "Cabin Air Heat Exchanger, Life Support System Specification for," dated 18 December 1964 gives the detailed design specifications.

4.1.6 CABIN AIR TEMPERATURE CONTROL SYSTEM. The cabin air temperature control system shall position the air bypass damper to proportion the air flow rate to the cabin air heat exchanger so as to maintain a preselected cabin air temperature.

The unit shall consist of the following components.

- a. Temperature Selector. A manually operated temperature selector shall be provided to permit selection of an automatically controlled cabin air temperature between 68° F and 85° F.
- b. Temperature Sensor. The air temperature sensor shall monitor cabin air temperature as required for proper operation of the controller. The sensor shall perform this function when subjected to a minimum ambient air velocity of 10 ft/min at a density of 0.051 lb/cu ft.
- c. Temperature Controller. The temperature controller shall actuate the damper actuator in response to input signals from the temperature selector and temperature sensor. The damper angular displacement shall be linear with temperature difference between the sensor and the setting on the selector.
- d. Damper Actuator. The actuator shall respond to signals from the temperature controller and position the air bypass damper in a manner that will minimize the difference between the selected cabin air temperature and the actual air temperature. The actuator shall be capable of moving the damper through an arc of

90 degrees, although the normal design damper traverse will be a 40-degree arc from 10 degrees open to 50 degrees open. The actuating time for a complete traverse shall not exceed one minute. Stall torque for the damper shall not be less than 50 in.-lb and not more than 200 in.-lb.

Manual control shall be possible in the event of a failure of the automatic control system or at the crew's option.

Convair Report No. 64-02017, "Temperature Control System, Specification for," dated 26 December 1963, as amended by Revision A, dated 18 December 1964, gives the detailed design specifications.

4.2 ATMOSPHERIC CONTROL.

The atmospheric control subsystem shall maintain a habitable atmosphere in the cabin by controlling the composition of the atmosphere, with the exception of water vapor content control, which is included in thermal control.

The composition of the atmosphere is controlled by:

- a. Removal and collection of CO_2 from the cabin air.
- b. Regeneration of O_2 from collected CO_2 .
- c. Removal of toxic and other contaminants from the cabin air.
- d. Providing O_2 and N_2 from storage for cabin leakage makeup, cabin and air lock repressurizations, and emergency metabolic oxygen.
- e. Circulation of air for both thermal and atmospheric control purposes.

To provide these functions within the spacecraft cabin test bed, the equipment is organized into the following subsystems.

- a. Oxygen Recovery.
- b. Atmospheric Pressurization.
- c. Contaminant Control.
- d. Ventilation and Flow.

All subsystems shall be compatible with the general system specifications. For example, each subsystem will be operable for at least one year. Weight, volume, and power shall be minimized where possible and be consistent with the requirements for reliability and safety. Waste heat shall be used wherever possible to reduce the requirement for electric power.

Figure 4.2-1 is a schematic of the integrated atmospheric control system. The detailed functional requirements are documented in Report No. 64-26215.

4.2.1 OXYGEN RECOVERY. The oxygen recovery system consists of three basic units: CO₂ concentration, CO₂ reduction, and water electrolysis.

4.2.1.1 CO₂ Concentration Unit. The CO₂ concentration unit shall be a regenerative unit capable of removing CO₂ (at an inlet partial pressure of 3.8 in. Hg) from the cabin air at a net rate of 9.28 lb/day. This CO₂ is to be delivered to an accumulator or vented to space at the crew's option. The unit shall deliver the collected CO₂ to the reduction unit at a constant pressure of 5.0 psig. The control of the actual flow to the reduction unit shall not be a requirement of the concentration unit but of the reduction unit.

The unit shall be designed for continuous operation and shall consist of at least the following components.

- a. CO₂ adsorbent beds (synthetic zeolite)
- b. Desiccant (water adsorbent) beds
- c. CO₂ storage or accumulator tank

Auxiliary components (blowers, pumps, heat exchangers, etc.) shall be provided, as required, to accomplish the prescribed task.

Automatic controls shall be provided to permit continuous automatic operation in either the thermal or vacuum regenerative (desorption) modes at the crew's option.

An adsorbent bed purge system shall be installed to limit the amount of cabin air delivered to the accumulator from the thermally desorbed adsorbent beds to no more than 0.05 lb/day. This purge system shall also minimize the amount of cabin air lost to space from the adsorbent canisters when operating in the vacuum desorb mode.

Cabin air shall be supplied to the unit at a pressure of 2 in. wg above cabin atmosphere (10-14.7 psia) and at a temperature of 34-55° F (saturated). The desiccant bed shall remove water vapor from this incoming air as required to protect the downstream adsorbent beds from water contamination. This excess water vapor shall be subsequently rejected (by means of thermal regeneration) to the cabin air.

In the event that an adsorbent bed is contaminated with water, manual overrides shall be provided to permit long-term desorption of the contaminated bed until it is capable of performing its normal CO₂-removal function.

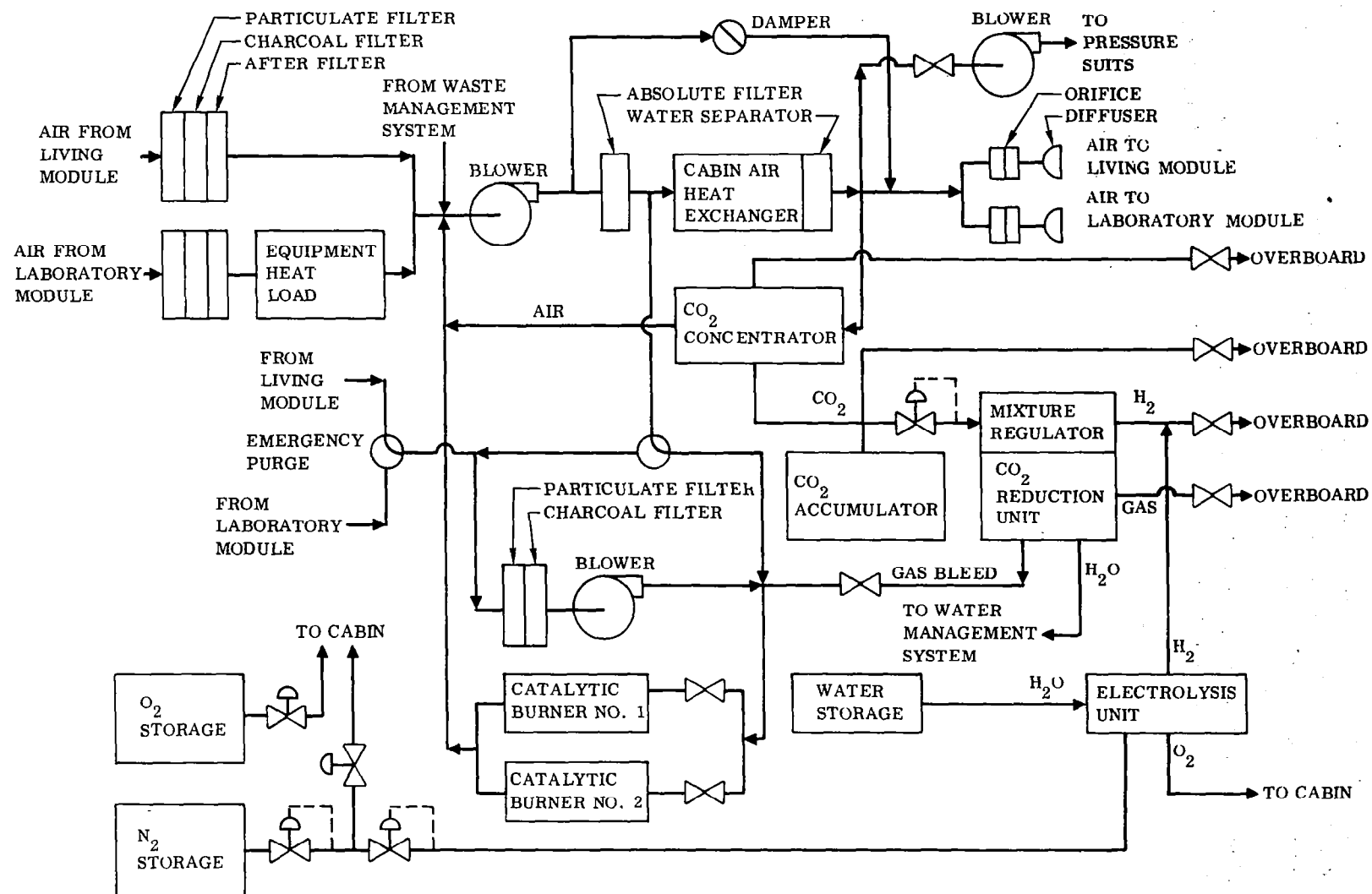


Figure 4.2-1. Atmospheric Control System Schematic

Process heat (DC-331 fluid) shall be available to the unit at a temperature of 375° F and a flow rate of 160 lb/hr. This process heat shall be used for the regeneration of the desiccant and adsorbent beds.

Liquid coolant (FC-75) shall also be available at a temperature of 45° F and a flow rate of 350 lb/hr to permit process cooling as required to optimize unit performance.

Figure 4.2-2 is a functional diagram of the CO₂ concentration unit showing desired process rates, modes of operation, and heat transport fluid availability.

The unit shall be insulated to minimize heat loss to the cabin air and shall not be larger than 20 × 20 × 36 inches. It shall be an operating prototype and, as such, shall incorporate the basic principles and fundamentals of flight-type systems. However, the unit does not necessarily have to be weight-, size-, or power-optimized.

Convair Report No. 64-02004, "CO₂ Concentration Unit, Life Support System Specification for," dated 11 September 1963, gives the detailed design specifications for this unit.

4.2.1.2 CO₂ Reduction Unit. The CO₂ reduction unit shall be based on the Bosch reaction and shall continuously produce water and carbon from CO₂ and H₂. The CO₂ and H₂ shall be fed to the unit from the concentrator and electrolysis unit respectively. The carbon shall be collected within the unit and manually removed and transferred to storage every 3-5 days. The water produced shall be fed to the electrolysis unit feed tank.

The unit shall consist of the following components.

- a. Bosch reactor.
- b. Regenerative heat exchanger.
- c. Condenser.
- d. Condensate separator and water delivery components.
- e. Recycle gas blower.
- f. Carbon collection and removal assembly and facilities.
- g. Sabatier reactor.

The basic reaction starts in the reactor but is not completed. Recycle through the reactor is required after the water produced is condensed out. Hence a regenerative heat exchanger is used to conserve heat and maintain the reactor temperature at about 1200° F. The carbon shall be collected within the unit so that it can easily be removed and stored in the zero-g environment.

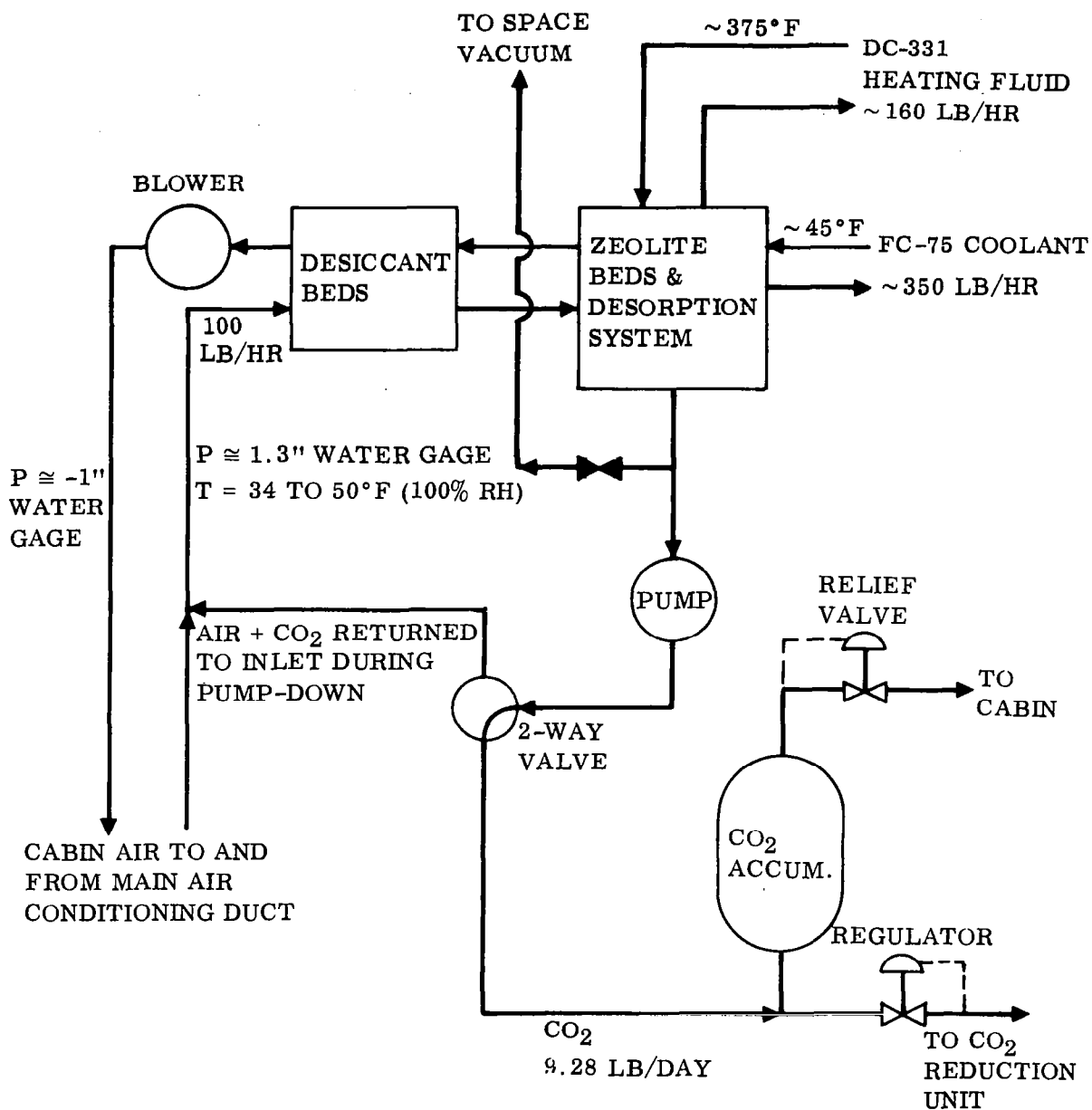


Figure 4.2-2. CO₂ Concentration Unit Schematic

The unit shall be constructed to minimize weight, volume, and power and maximize reliability and safety. Waste heat shall be used, where possible, to reduce the power requirement.

Figure 4.2-3 is a schematic diagram of the CO₂ reduction unit. The unit shall be designed to continuously process not less than 9.28 lb/day of CO₂ according to the net reaction:



The CO₂ shall be supplied at a temperature between 50° F and 400° F. Both CO₂ and hydrogen gases shall be available to the unit under positive pressures. The units and interconnecting valving are such that about 3.5-5 psig will be maintained in the CO₂ line and 6.5-9 psig in the H₂ line. Air contamination of the inlet CO₂ shall not be more than 0.1 lb/day, and the unit shall provide for handling this contaminant. The water produced in the unit shall be fed to a water electrolysis feed tank at a pressure of about 7 psig.

Carbon-collection, removal, and transport facilities requiring a minimum of manual attention shall be provided. Permanent storage facilities (racks, cabinets, etc.) for carbon are not a part of the CO₂ reduction unit.

The reactor heat input shall be by waste heat and electrical heaters. The waste heat transport loop will contain DC-331 at an approximate temperature of 375° F. The internal operating pressure shall be controllable between about 10 and 20 psia. Catalyst shall be provided for six months' reactor operation. Insulation shall minimize heat losses and temperatures of exposed surfaces.

The condenser of the unit shall be designed to utilize an FC-75 coolant at 32° ± 2° F, and the flow shall be about 350 lb/hr. The condenser shall be insulated to prevent condensation on the external surfaces.

Sensors, instrumentation, and controls shall be provided for the operation and monitoring of the unit. Continuous monitoring instrumentation shall be compatible with display on a centralized panel in the space vehicle simulator. Critical parameters and parameters that identify an impending failure shall be instrumented to permit remote electrical readout or alarm.

The reactor shall provide an alternate mode of operation forming methane and water at a temperature of about 600° F with a nickel catalyst:



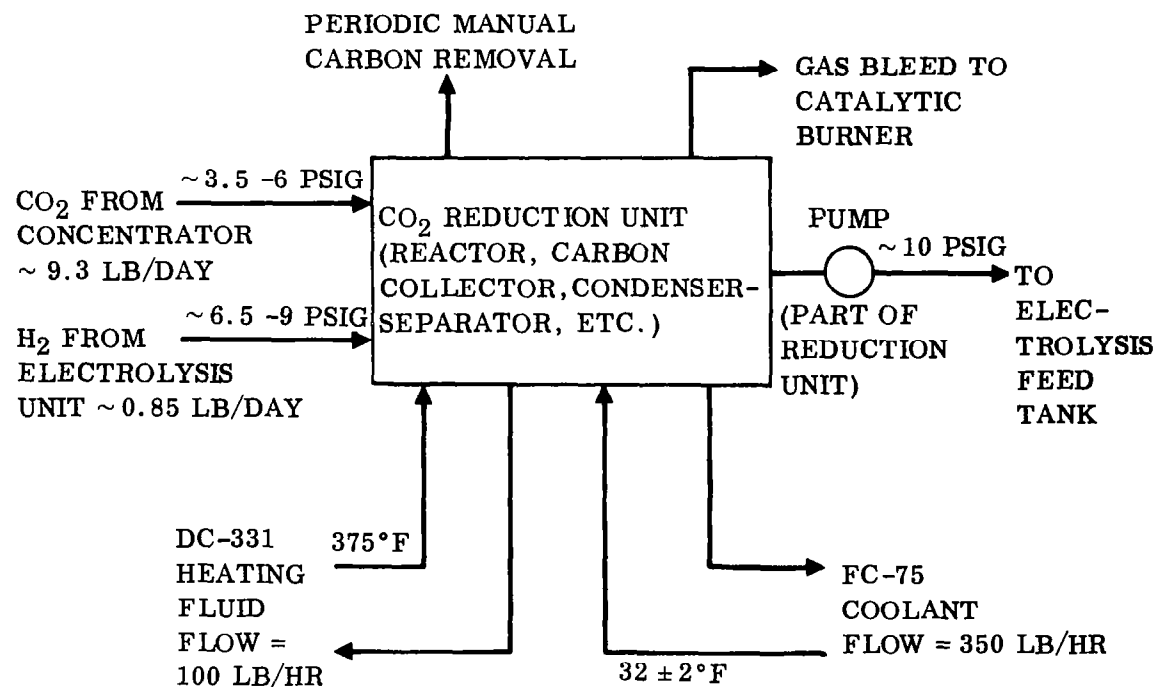


Figure 4.2-3. CO₂ Reduction Unit Inflows and Outflows

The unit design shall allow switching to this mode of operation. Since hydrogen will be stored, however, only about half the CO₂ will be reacted in this alternate mode of operation. The noncondensable reaction products shall be jettisoned to the vacuum of space.

4.2.1.3 Water Electrolysis Unit. The water electrolysis unit electrolyzes water to obtain oxygen for the crew.

The unit shall consist of several identical modules with convenient disconnect provisions to permit replacement of one or more. When assembled, all electrical and fluid connectors shall be located on the same surface of the unit. There shall be access to terminals for each cell to permit voltage measurement and/or shorting out of one or more individual cells. Polarity shall be clearly marked at all terminals.

The unit shall utilize FC-75 for a coolant. It shall electrolyze water introduced to the unit from the CO₂ reduction unit and the water management system. The electrolyte side of the unit shall be kept under pressure by the feed tank, which will utilize pressurized air at about 7 psig. The O₂ and H₂ produced in the unit shall be available in separate lines.

Manual on-off controls and disconnects for electrical power, water feed, and coolant flow shall be provided. Also, automatic controls shall be included to preclude damage to the unit if there is an interruption in the coolant or water inflow.

Figure 4.2-4 is a schematic of the electrolysis unit. Water from the feed tank at 50° to 90° F feeds the electrolysis system at about 7 psig. The pressure shall be reduced to about 5 psig on the electrolyte side of the cells and shall be maintained by means of a pressure regulator valve.

The input water minimum quality will be:

pH factor	6-8
Conductivity, maximum	100 micromhos/cm
Total solids, maximum	100 ppm
Ammonia	20 ppm
Cl ⁻	20 ppm
SO ₄	20 ppm
Urea	20 ppm

The unit shall be capable of producing O₂ and H₂ at flow rates of 8.0 and 1.0 lb/day respectively. At these outflow rates, the operating potential at the cell terminals

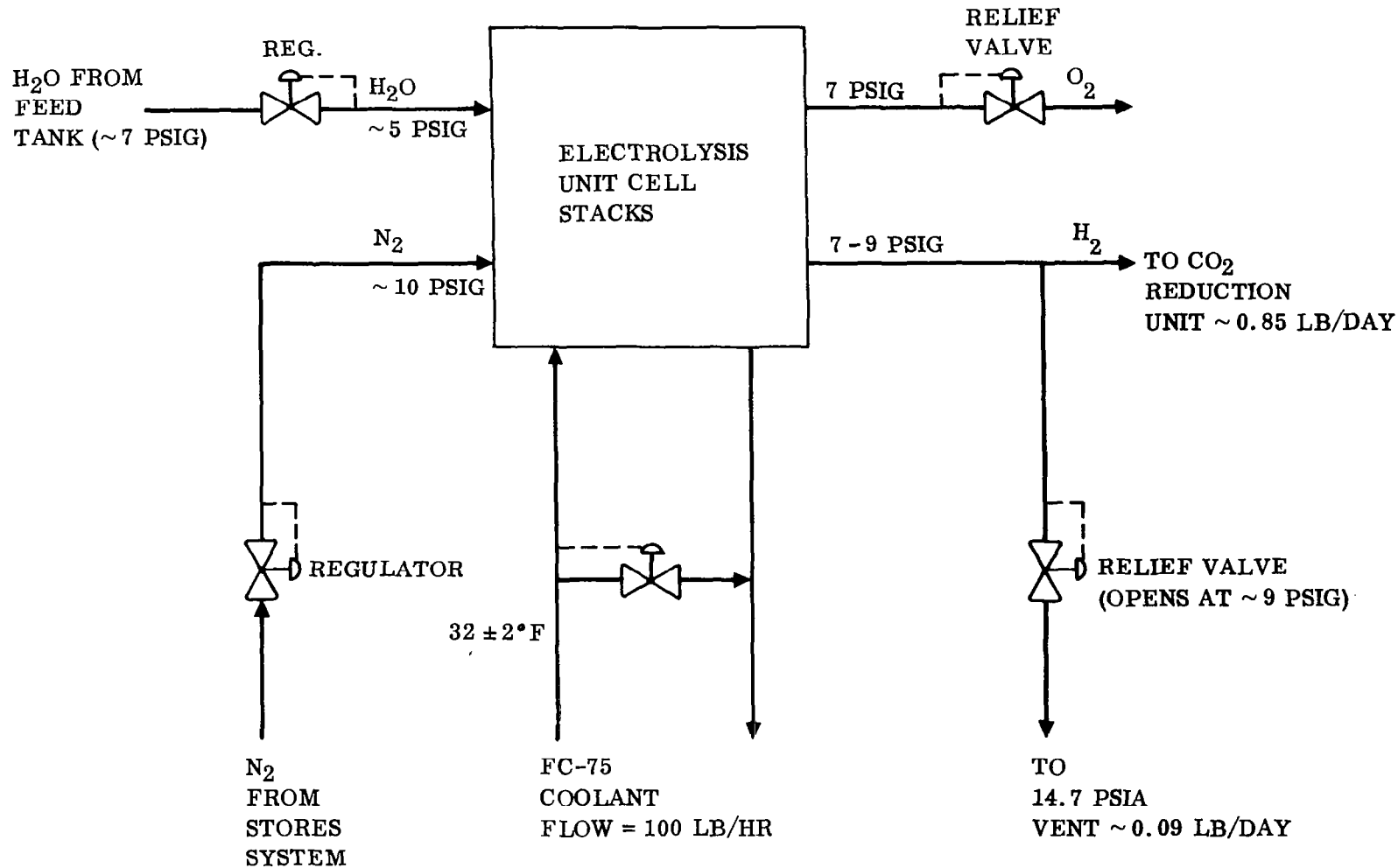


Figure 4.2-4. Water Electrolysis Unit Inflow and Outflow Schematic

shall be 28-30 vdc. The pressure of the output gases shall be maintained at about 7 psig by pressure relief valves.

Heat shall be carried out of the unit by the coolant supplied at a temperature of $32^{\circ} \pm 2^{\circ}$ F. The maximum coolant flow is 100 lb/hr. The voltage applied to the unit may vary from 24 to 32 volts without causing a malfunction in performance.

4.2.2 ATMOSPHERIC PRESSURIZATION. The concept recommended for the operational spacecraft was subcritical storage with vapor (gaseous) delivery; however, a supply system of high-pressure bottles shall be used in the test bed. The system is simple, reliable, inexpensive, and safe. The test bed shall also incorporate vacuum pumps to simulate the low-pressure environment and the specified leakage of gas out of the bed. Control of the test-bed pressure and leakage is to be accomplished entirely from the outside, although some functions will be duplicated inside the test bed to offer a means of alternate control to the crew. Figure 4.2-5 is a schematic of the system.

Pressure within the tank shall be controlled by means of two vacuum pumps. For quick pulldown of the test bed, a 350-cfm vacuum pump shall be provided. This pump shall also provide the vacuum source for the CO₂ concentration unit when used in the vacuum desorption mode and as the vacuum source for venting gases from the feces dryer. The vacuum source for the subsystems shall contain a cold trap utilizing LN₂ to prevent liquids from entering the vacuum pump. In addition, this pump is to be used to adjust pressure in the air lock for ingress to and egress from the test bed.

After pulldown with the large pump, pressure shall be maintained by means of a 5-cfm pump that maintains the desired outflow from the cabin to simulate leakage. Shutoff valves are to be provided in the lines to the pumps.

A negative pressure relief valve shall be provided to open at 6.7 psi below the surrounding ambient if the internal pressure drops below a specified crew safety value. When tests at pressures lower than the negative relief setting are necessary, the relief valve may be removed and the opening of the tank sealed by means of a plate attaching to the flange on the tank coupling.

Simulation of the specified spacecraft leakage rate of 33-1/2 lb/mo shall be accomplished by metering O₂ and N₂ in the required proportions to the tank.

In addition to the simulated spacecraft leakage, leakage into the test bed must be determined and accounted for.

Because the O₂ partial pressure is 160 mm Hg at a cabin pressure of 10.0 psia, the N₂ in the air leaking into the tank will cause N₂ enrichment of the cabin atmosphere. The extent to which O₂ and N₂ stores will be provided shall be determined after test-bed leakage has been experimentally established.

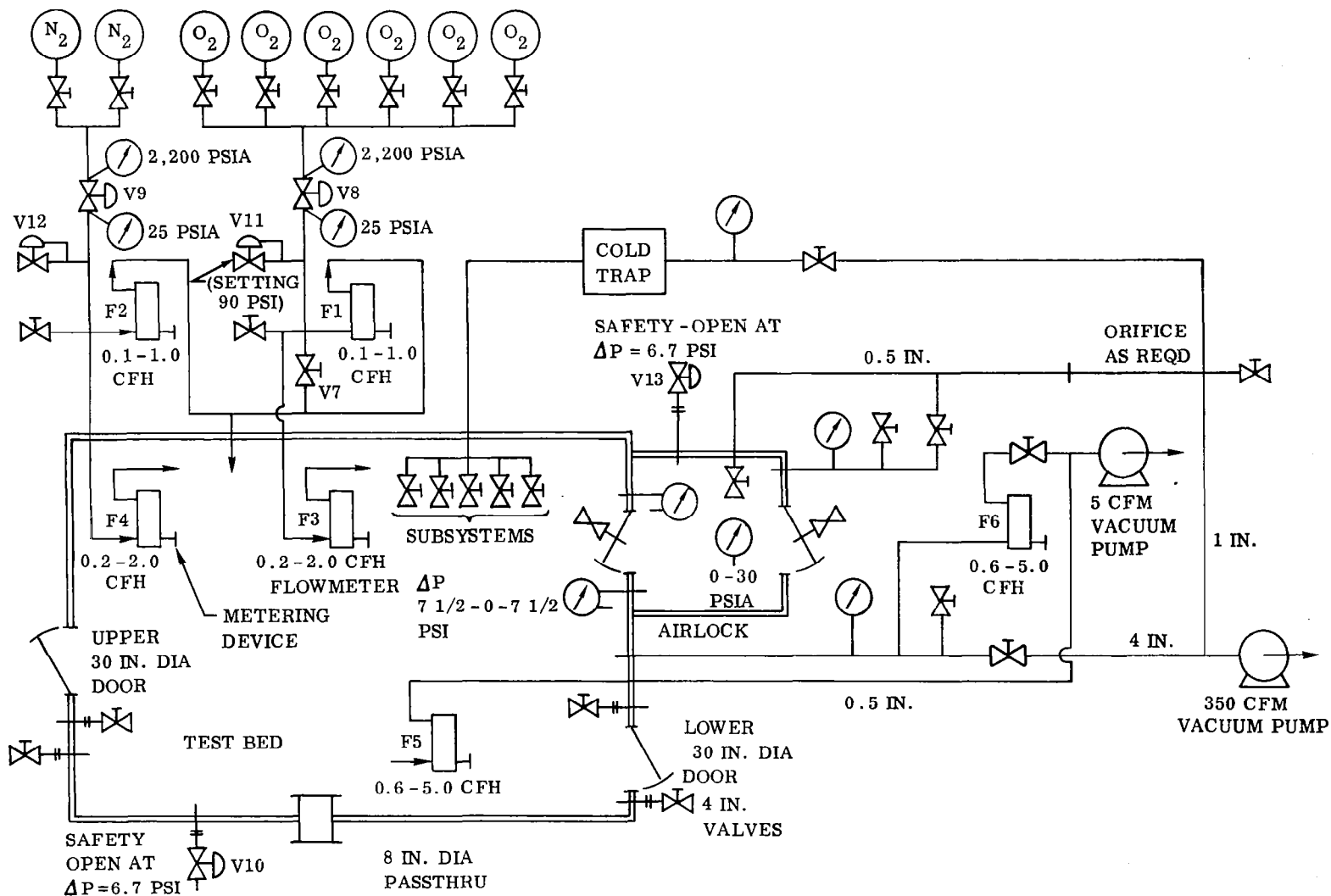


Figure 4.2-5. LSS Test Bed Pressure Regulation Schematic

Separate O₂ and N₂ metering flowmeters shall be installed inside the test bed to allow crew members fine control in maintaining O₂, N₂ proportions, simulating the heater control that would be necessary to adjust flow from the subcritical stores of an actual spacecraft. An air lock on the test chamber shall be provided for entry and exit.

4.2.3 CONTAMINANT CONTROL. The contaminant control units on the prototype LSS shall include two charcoal filters, two high-temperature catalytic burners, and particulate filters.

4.2.3.1 Charcoal Filter. A filter is required to remove trace contaminants and odors from the cabin atmosphere. Activated charcoal adsorbs many of the expected organic contaminants, including hydrocarbons of medium and high boiling points, alcohols, ketones, aldehydes, mercaptans, organic acids, halogenated materials, and ozone. The charcoal will not adsorb significant amounts of carbon monoxide, carbon dioxide, or methane, which are removed by other subsystems. The air passing through the filter beds shall have a maximum temperature and relative humidity of 80° F and 60 percent respectively. Air velocity approaching the charcoal filter should not exceed 100 fpm if the residence time is to be adequate to attain efficient adsorption of contained contaminants and odors.

4.2.3.2 Catalytic Burners. The catalytic burners remove hydrogen, carbon monoxide, methane, and other hydrocarbons that pass through the charcoal filters. The burner oxidizes the hydrogen to water vapor, the carbon monoxide to carbon dioxide, and the methane and other hydrocarbons to water vapor and carbon dioxide. The water vapor and carbon dioxide products are later removed from the atmosphere by other subsystems.

The catalytic burner subsystem shall consist of two high-temperature burners capable of operation in either series or parallel. The catalyst shall contain approximately 10 percent by weight of Li₂CO₃ to remove any acid gases produced in the burners. The burners shall be insulated to minimize heat losses and for crew safety. Figure 4.2-6 is a schematic of the subsystem.

The nominal performance requirement is for 4.95 lb/hr of air through the main burner with the standby burner not in operation. The standby catalytic burner may be placed in either series or parallel with the main burner.

The air to the burner shall pass through a regenerative heat exchanger and then be heated by an electric heater to maintain an operating temperature range of 700-800° F. The catalytic burners will each require power for the heaters at a maximum level of 110 watts. For off-design performance, the power for each must be available simultaneously. A temperature controller shall be used to monitor and control the air temperature by automatically cycling the electric heater as required.

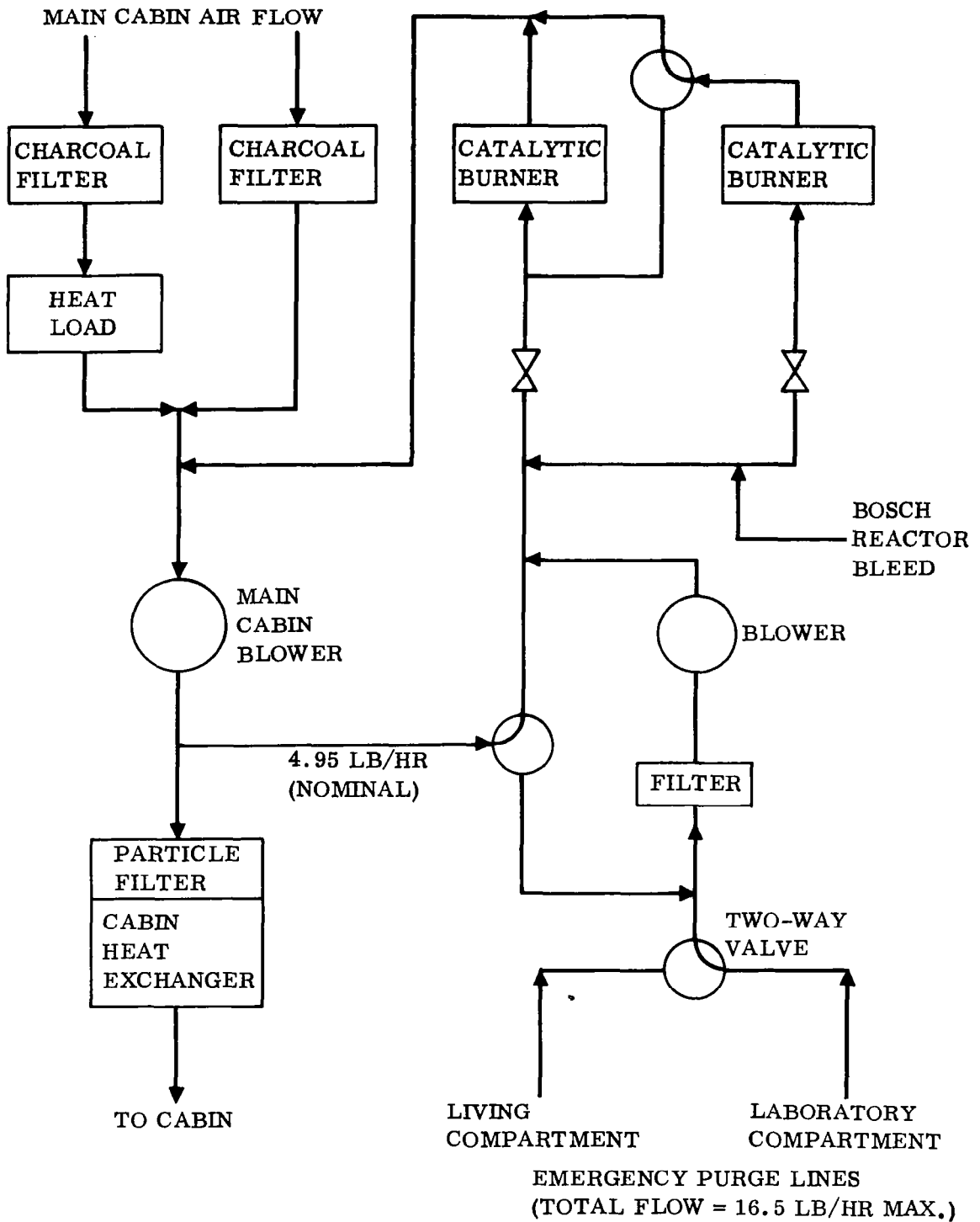


Figure 4.2-6. Contaminant Control System Flow Schematic

4.2.3.3 Particulate Filters. All particulate matter that can impair the operation or unnecessarily increase the task of a component shall be removed. An inspection of the components in the air conditioning circuit reveals that the air going to the catalytic burner and the cabin air water separator must be filtered to prevent degradation of unit performance.

Particulate matter greater than 5 microns in diameter could conceivably collect in, and restrict the air flow through, the catalytic burner. Similarly, particles of the same diameter could plug the small capillary holes in the porous plates of the water separator.

A 5-micron filter located in the duct upstream of these units would satisfy these filtering requirements. However, it would not remove aerosols (normally larger than 0.3 micron) from the air stream. These aerosols could combine with the condensate formed in the cabin air heat exchanger and subsequently enter the water processing circuit. Their presence in the water would impose additional requirements upon the recovery system. Maximum lung retention, and consequent lung damage, occurs with particle sizes in the range of 0.5-5.0 microns. Hence an absolute filter capable of removing particles down to 0.3 micron shall be installed in the air circuit upstream of the inlets to the catalytic burner and cabin air heat exchanger.

4.2.4 VENTILATION AND FLOW. The ventilation system shall provide an air flow rate that satisfies the thermal control requirements and introduces this air into the cabin in a manner conducive to the comfort and safety of the crew. Proper ventilation, therefore, calls for:

- a. Creating an air flow rate through the thermal control system that will satisfy the heat transfer equipment requirements without reducing the temperature of the air to a level that will prevent it from being comfortably introduced into the compartments.
- b. Introducing the conditioned air into the cabin in a manner that will reduce the air motion and temperature differences between the conditioned air and cabin air to acceptable limits before the air enters the occupied zones of the compartments.
- c. Creating adequate air motion within the occupied zones of the compartment to ensure uniform distribution of the conditioned air without causing discomfort to its occupants.
- d. Returning the cabin air to the conditioning system for processing without creating regions of excessive velocities or noise in the occupied zones.

4.2.4.1 Cabin Air Outlets. The air outlets must induce high entrainment to create the maximum air motion within the occupied zones of the cabin. The outlet must also be capable of introducing the conditioned air into the cabin in a manner that will reduce the air motion and temperature difference between the conditioned air and cabin air to acceptable limits before the air enters the occupied zones of the compartments.

The outlet that most nearly satisfies these requirements is a partial spreading type, frequently referred to as a diffuser. The outlets shall be located near the ceiling of each compartment and shall produce one or more horizontal jets. The high-velocity gradient across these jets causes large amounts of cabin air to be induced into, and mixed with, the conditioned air stream within a short distance of the outlet. This mixing effect rapidly reduces the temperature differences between the conditioned air and cabin air and makes it possible to introduce conditioned air into the cabin at temperature differences of up to 35° F without causing discomfort to its occupants.

4.2.4.2 Recirculation Fans. Laboratory investigations have been conducted at a number of institutions to determine the entrainment and induction capabilities of various outlet geometries. The data accumulated has been sufficiently detailed to permit the prediction of ventilation jet characteristics under zero-g conditions. The results are given in Convair Report 64-26217, "Prediction of Ventilation Jet Characteristics for a Zero Gravity Environment," January 1964.

These results indicate that ventilation rates of 4.2 and 6.8 compartment volumes per hour will be required to satisfy the minimum ventilation requirements (10 fpm) under 1-g and zero-g conditions respectively.

4.2.4.3 Main Blower. The main blower shall convey the required amount of air through the primary loop of the conditioning system consisting of the particulate filter, charcoal filter, cabin heat exchanger, and water separator. It shall deliver the air to the cabin air outlet with sufficient static pressure to ensure proper air outlet performance. The air ventilation system static pressure profile for this system is shown in Figure 4.2-7.

The unit shall be an axial-flow blower using a 208-volt, 400-cps, three-phase source. The fan-motor combination shall be capable of delivering 300 cfm of cabin air at a static pressure of 5.2 in. wg and a density of 0.0500 pound per cubic foot. This corresponds to 900 lb/hr of air at 75° F and 10.0 psia.

4.3 WATER MANAGEMENT

The primary task in maintaining a usable water supply in the closed environment of a spacecraft is reclaiming waste waters. In addition to waste water reclamation, facilities for the following must be available.

- a. Storage of raw urine, used wash water, and humidity condensate.
- b. Collection of reclaimed water for quality analysis (holding tanks).
- c. Storage of purified water.
- d. Transfer of water to and from tanks and between reclamation systems when necessary.

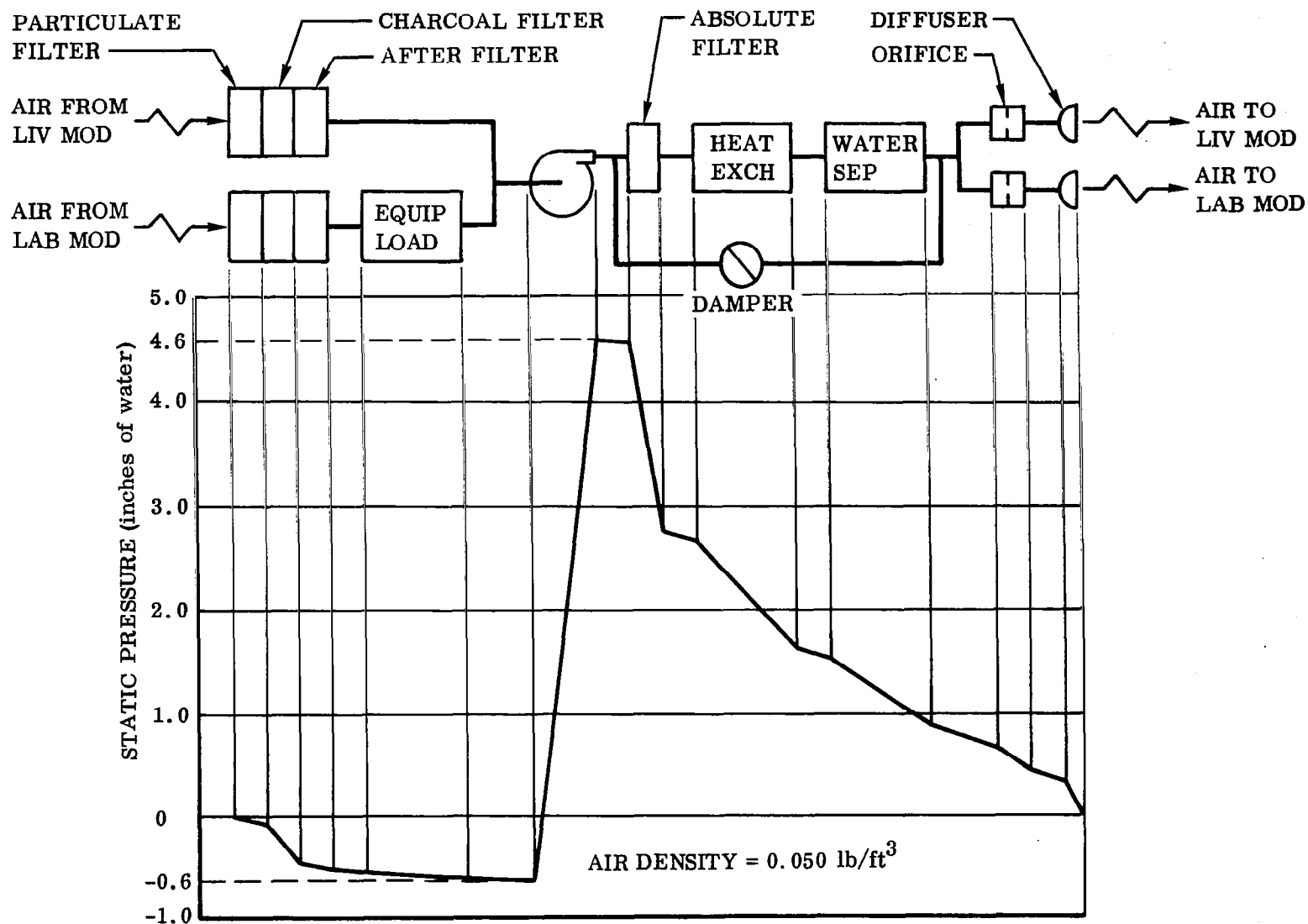


Figure 4.2-7. System Static Pressure Profile

- e. Storage of emergency water supplies.
- f. Heating of potable water.
- g. Cooling of potable water.
- h. Dispensing of water for drinking, food preparation, and washing.
- i. Collection of waste waters and water from the CO₂ reduction unit.
- j. Provision of water for electrolysis.
- k. Provision for cleansing and disinfecting any fresh water tanks that may be contaminated.

Heating, cooling, and dispensing of potable water was treated as part of the food subsystem. Facilities for dispensing wash water and collecting used water were included in the personal hygiene subsystem. Humidity condensate is delivered directly from the main cabin air dehumidifier to the water management subsystem.

4.3.1 DESCRIPTION OF SUBSYSTEM. Figure 4.3-1 is a schematic of the water management subsystem. The valve positions for "normal mode" operation is shown, except that valves 2A, 2B, and 2C would be turned off after waste water is transferred to the processing unit pretreatment tanks. Zero-g tanks required for storage of the waste and recovered waters are shown with connections to a compressed gas source. The pressurized gas will serve to collapse bladders against the water inside the tanks when water is to be transferred from these tanks. Design of the tanks allows for approximate water-level indication. The major components of the subsystem can be summarized as follows:

- a. Two waste-heat air evaporation units provide for recovery of water from the three waste water tanks. An on-line multifiltration unit is included in the subsystem for emergencies only. During normal operation, urine is to be processed in one of the air evaporation units and waste wash water and humidity condensate are processed in the second unit.
- b. Tanks are provided for collection of waste waters, collection and holding of recovered waters, storage of electrolysis water, storage of reclaimed water, and storage of emergency water supply.

4.3.1.1 Waste Water Collection Tanks

a. Urine (CT-3)

Capacity: 46 lb

Function: Collection of urine delivered to the collection unit (in the waste management subsystem). Urine from this tank is fed directly to processing unit No. 2.

NORMAL MODE

NOTE: PRESSURE REGULATOR TOLERANCES
FOR PR-1 AND PR-3 = ± 0.15 PSI AND FOR
PR-2 = ± 0.45 PSI

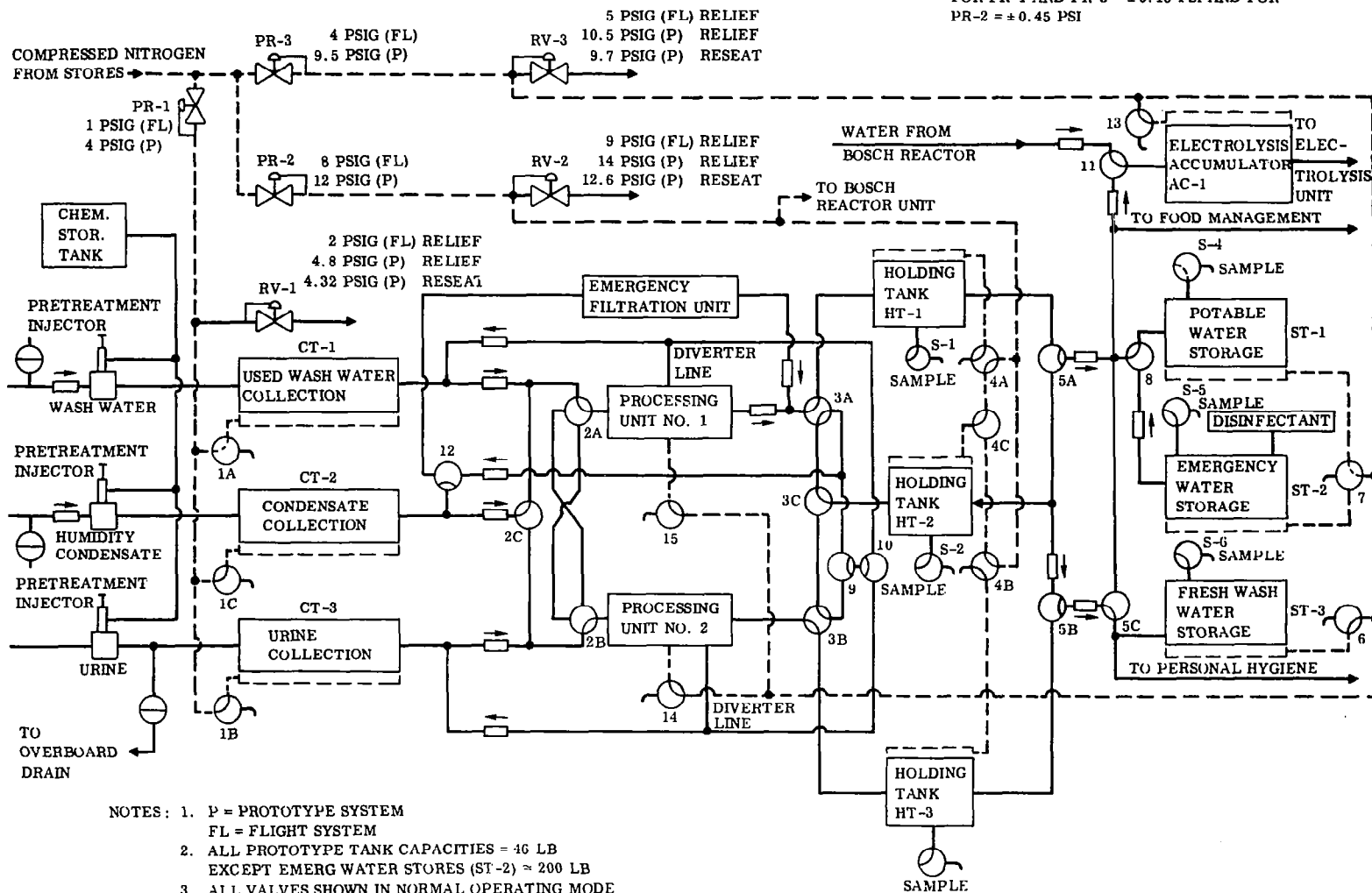


Figure 4.3-1. Integrated Water Management System Revised Schematic

b. Used Wash Water (CT-1)

Capacity: 46 lb

Function: Collection of used wash water delivered from the personal hygiene subsystem. Used wash water from this tank is fed directly to processing unit No. 1.

c. Humidity Condensate (CT-2)

Capacity: 40 lb

Function: Water from the main cabin air dehumidifier continuously flows to this tank. Waste water from this tank is fed to processing unit No. 1 during normal operation. In emergency situations, this waste water is processed through the emergency filtration unit.

4.3.1.2 Waste Water Processing Units

a. Processing Unit No. 2

Type: Waste heat air evaporation

Capacity: Capable of processing 32.8 pounds of waste water in 16 hours.

Function: Processing unit No. 2 will reclaim water from urine during the normal mode of operation. The unit delivers recovered water (free of non-condensable gases) to a holding tank that will be vented. The unit is expected to recover at least 95 percent of the water contained in raw urine.

b. Processing Unit No. 1

Type: Waste heat air evaporation; identical to processing unit No. 2.

Capacity: Capable of processing 32.8 pounds of waste water in 16 hours.

Function: Processing unit No. 1 will reclaim water from used wash water and humidity condensate during the normal mode of operation. The unit delivers recovered water (free of noncondensable gases) to a holding tank that will be vented. The unit is expected to recover 97 percent of the water contained in used wash water and 99 percent of the water contained in humidity condensate.

c. Emergency Filtration Unit

Type: Multifiltration (activated charcoal, in ion-exchange resin, and a bacteria filter)

Capacity: Capable of processing 19.6 pounds of humidity condensate in 16 hours for 17 days.

Function: Will purify humidity condensate to produce potable water during periods of emergency operation (loss of both air evaporation processing units). A recovery efficiency of 99 percent is expected from the multifiltration unit.

4.3.1.3 Holding Tanks

a. Holding Tank No. 3 (HT-3)

Capacity: 41 lb

Function: Under normal operation, recovered urine from processing unit No. 2 is collected in this tank. The gas side of the tank is vented to ambient during collection of processed waste water so that the internal pressure is 0 psig. While water is collected in this tank, an in-line conductivity probe within the processing unit continuously monitors the chemical purity of recovered water. In the event of a failure of processing unit No. 1, this tank, cycled with holding tank No. 2, will be used to collect all recovered waste water and will hold the water during an analysis for bacteria. Water not meeting quality standards is transferred back to one of the waste water collection tanks for reprocessing. Recovered water meeting quality standards is transferred to the wash water storage tank (under normal operating conditions) and to the potable water storage tank (in the backup mode if processing unit No. 1 has failed). Water transfer is accomplished by pressurizing the tanks.

b. Holding Tank No. 2 (HT-2)

Capacity: 41 lb

Function: During normal operation, waste water processed through processing unit No. 1 (used wash water and humidity condensate) is collected in this tank and analyzed for bacteria at the end of a batch operation. While water is collected in this tank, an in-line conductivity probe within the processing unit continuously monitors the chemical purity of recovered water. The gas side of the tank is vented to ambient during collection of processed waste water so that the internal pressure is 0 psig. In the event of a failure of either processing unit, this tank is used for collection of all recovered water and cycled with a second holding tank; it will hold this recovered water for a quality check, including analysis for bacteria. Recovered water not meeting quality standards is transferred back to one of the waste water collection tanks for reprocessing. Recovered water meeting quality standards is transferred to the potable water storage tank.

c. Holding Tank No. 1 (HT-1)

Capacity: 41 lb

Function: Same as holding tank No. 2, except that water from processing unit No. 2 is not collected in this tank when processing unit No. 1 fails.

d. Electrolysis Accumulator (AC-1)

Capacity: 9 lb

Function: Collects and temporarily holds water given off by the Bosch CO₂ reduction unit. The accumulator serves as a constant supply of water for the electrolysis unit. Makeup water required for electrolysis is periodically transferred from the potable water storage tank to the accumulator.

4.3.1.4 Fresh Water Storage Tanks

a. Wash Water (ST-3)

Capacity: 28 lb

Function: Storage of water recovered from urine to be used for washing.

b. Potable Water (ST-1)

Capacity: 66 lb

Function: Storage of recovered wash water and humidity condensate. Water from this tank is used for food reconstitution, drinking, and electrolysis makeup.

c. Emergency Potable Water (ST-2)

Capacity: 205 lb

Function: Storage of emergency water supply. A sample port is attached to this tank so that samples can periodically be taken and analyzed for purity.

4.3.2 WATER UTILIZATION AND PURITY

4.3.2.1 Water Balance. Recovered waste waters are used for drinking, food preparation, washing, and electrolysis. Table 3.3-I gives a breakdown of the water sources and uses. The water allowance shown for consumption is maximum; the quantities shown for urine and fecal waste waters are average. Some water is lost in discarded food. An estimate of this loss, based on an estimated food waste of 0.20 lb/man-day and a 1-percent loss of water in beverages, is included in the water balance.

Recovery efficiencies used to determine the amount of water recovered were those believed to be obtainable in each of the waste water processing units.

4.3.2.2 Recovered Urine Water. Recovered urine water, along with some makeup potable water when required, is used for washing.

Although under normal conditions recovered urine water will not be used for human ingestion (for psychological reasons), and thus bacteriological tests were not planned for the normal operating mode, the urine processing equipment is capable of producing potable water from urine. Tentative potable water standards are as follows.

pH factor	6-8
Conductivity, maximum	100 micrmhos/cm
Total solids, maximum	100 ppm
NH ₃	Less than 20 ppm
Cl	Less than 10 ppm

SO ₄	Less than 10 ppm
Urea	Less than 0.5 ppm
Bacteria	Less than one colony per ml
Organoleptic Test	
a	No visible turbidity
b	No observable color
c	No unpleasant odor
d	No unpleasant taste

The water recovered from urine is used as wash water and is to be post-treated with benzalkonium chloride (BAC) to provide a cleansing agent considered to provide both bactericide and detergent properties. The BAC is essentially an ammonium salt and is removed from the waste wash water by activated charcoal, ion exchange, or phase change.

4.3.2.3 Recovered Wash Water. Water reclaimed from used wash water is to be analyzed for potability. All the reclaimed wash water determined to be potable will be transferred to the potable water storage tank where reclaimed humidity condensate is also stored.

The recovered humidity condensate and recovered wash water meeting potable water standards is held for use in the potable water storage tank. Of the average total potable water supply of 8.04 lb/man-day (recovered condensate and wash water), 7.65 lb is for drinking and food preparation, 0.20 lb for electrolysis makeup and 0.17 lb for washing.

4.3.2.4 Bosch Reactor Water. Bosch reactor water averaging 1.9 lb/man-day is to be transported to an accumulator and used for electrolysis along with makeup from potable water storage.

4.3.3 SUBSYSTEM OPERATION

4.3.3.1 Reliability Considerations. To achieve the reliability required, the subsystem must be designed to operate in three modes as follows.

- a. Normal Mode. The two air evaporation units operate according to design specifications and purify waste water as required (design continuous level).
- b. Backup Mode. A breakdown of one of the air evaporation processing units, requiring additional processing by the other unit (minimum continuous level). Operation at the minimum continuous level is defined as follows:
 1. The surviving air evaporation unit operates 25 percent longer than under normal operation (13 percent longer for the prototype system).

2. Water allocated for washing is reduced by 50 percent (reduced by two-thirds for prototype system).
 3. There is no reduction in electrolysis water makeup.
 4. Water allocated for drinking and food rehydration remains normal.
 5. Water allocated for washing comes from potable supply.
- c. Emergency Mode. Breakdown of both air evaporation processing units. Emergency operation is defined as follows:
1. Humidity condensate is processed in the emergency filtration unit. Water requirements are derived from the recovered condensate and emergency stores.
 2. Water allocated for drinking and food rehydration remains normal.
 3. There is no reduction in electrolysis water makeup.
 4. No water is allocated for washing.

Design Requirements. Equipment must be designed to assure successful operation of the water management subsystem under any of the three modes of operation. The following criteria must be adhered to in order to achieve this assurance.

No failure of the primary mode shall prevent initiation of the secondary (backup mode).

No single inadvertent manual switching sequence results in irreversible component failure; i.e., initiates a loss of function that cannot be regained by correction of the procedural error if accomplished in a reasonable time.

The equipment must be amenable to maintenance demands of the mission. Minimizing the requirement for servicing and preventive maintenance and maximizing the potential for corrective maintenance is a major contributor to subsystem reliability. Subsystem downtime is the major parameter involved in the design analysis. Assumptions concerning the in-flight availability of spare parts and repair materials or special tools must be reflected in the weight estimates for the operational items.

The restrictions imposed on the design with respect to servicing and preventive maintenance should be followed as far as practicable in the design for repair by the operational crew.

The matching of estimated downtimes in the maintainability analyses with the stated allowable downtimes is a key to the operational reliability of the subsystem. The degree of independence between management functions has a marked effect on the allowable downtimes for each function.

The switching functions for any given sequence or mode of operation must be minimized. Care must be exercised to avoid compromising the integrity of the equipment items and processes involved; and increasing the equipment complexity of the subsystem.

Operational Reliability, Maintainability and Safety. Reliability is defined as the probability that the subsystem will perform its basic function successfully for the specified life without failures requiring a shutdown for periods exceeding the allowable maintenance downtimes.

Safety is defined as the probability that the primary backup and emergency modes of attaining subsystem functions will operate so as not to endanger the life of the crew during the normal mission, emergency, or specified alternate mode periods.

Attention must be given to the design of simple and functional components, processes, and process controls that have inherently low failure probabilities, are characteristically independent of other failures within the subsystem, and have high assurance of repair upon failure. From the safety standpoint, no single failure can be allowed to directly create a crew safety hazard.

In addition design approaches that increase the direct and continuous monitoring capability of the crew on each function and its processes and thereby allow for timely corrective action must be considered.

The subsystem shall be required to operate under the conditions stated herein with a reliability of at least 0.990.

The types and frequency of failure together with the repair capability of the crew and the repair potential of the equipment system shall be such that subsystem availability of 0.982 is attainable. Availability is the fraction of total desired operating time that the equipment is actually operable.

The maximum allowable downtime of the subsystem for servicing and preventive maintenance is two hours (continuous). The maximum allowable downtime for corrective maintenance is six hours, with an average downtime not to exceed one hour.

Typical servicing and maintenance tasks are changing of filters and wick cartridges, replenishment of pretreatment chemicals, cleaning of surfaces exposed to spillage and process materials, and inspection of exposed seals subject to wear.

Malfunctions requiring corrective maintenance are:

- a. Clogging of feed lines or feed control components.
- b. Leakage of air from an air evaporation unit.

- c. Failure of an air circulation fan.
- d. Failure of liquid-gas separator.
- e. Instrumentation or control failures.

Routine maintenance of the emergency filtration unit would consist of replacement of charcoal, ion-exchange, and bacteria filters, if required. Corrective maintenance would be required for clogging of feed lines or a feed metering pump; or a breakdown of a metering pump.

Other repair maintenance requirements would arise in the water management subsystem if any of the following defects occurred:

- a. Leakage of waste or reclaimed waters from fittings or valves or tanks.
- b. Transfer valve failure.
- c. Air leakage from pressurized tanks or air lines.
- d. Contamination of holding tanks or potable water storage tanks with impure water (requiring cleansing of the tanks).

4.3.3.2 Subsystem Operating Modes. (See Convair Report No. 64-26219, "Water Management Subsystem Operational Description".)

a. Normal Mode

1. **Urine Water.** Urine collected in the waste management subsystem is delivered to the pressurized urine collection tank. Liquid disinfectant solution, periodically sprayed into the urine collector to keep it sanitary, passes into the urine collection tank. There the disinfectant, plus additional pretreatment chemicals injected into the dilution chamber, prevent bacterial growth, with the latter preventing urine decomposition. To start the processing of urine, the contents of the urine collection tank are transferred to the pretreatment tank in processing unit No. 2, where the operation of the unit is initiated. Recovered urine water is pumped to holding tank No. 3, which is vented during processing. The recovered water quality is continuously monitored by an in-line conductivity probe, and automatic recycle is initiated if water of high conductivity is being produced. At the end of a batch operation, the recovered urine water is sampled and checked for impurities. Water meeting standards is transferred to the wash water storage tank, where BAC is added to prevent bacterial growth and to provide detergent qualities. Reclaimed water not meeting standards is transferred back to the urine collection tank for reprocessing.
2. **Bosch Reactor Water.** Water produced in the Bosch reactor is transferred to the electrolysis accumulator along with electrolysis makeup water from potable water storage.

3. **Used Wash Water.** Used wash water originating in the personal hygiene subsystem is transferred, as produced, to the pressurized wash water collection tank. Pretreatment transfer and the operation of the unit is similar to urine processing. Recovered wash water (along with recovered humidity condensate) is transferred to holding tank No. 2 or No. 1. As in processing unit No. 2, the recovered water quality is continuously monitored and recycled in case of high conductivity. The recovered water is checked for bacteria (requiring about 24 hours, during which time the second holding tank is available for use). Recovered water meeting purity standards is transferred to the potable water storage tank. Water not meeting purity standards is transferred back to the used wash water collection tank for reprocessing.
 4. **Humidity Condensate.** Condensate from the main cabin air dehumidifier is delivered continuously through the pretreatment dilution circuit to the condensate collection tank. Humidity condensate is recovered in processing unit No. 1 in the same manner as used wash water.
- b. **Backup Mode.** The two air evaporation units are sized and interconnected so that breakdown of either processing unit will allow operation of the working unit for processing of all waste waters. The alternate source of recovery processing provides additional time for repairs in addition to reducing the seriousness of the failure. This, in turn, increases the probability that normal resupply will be adequate.

Repair or replacement of critical components under weightless conditions is a specific maintenance requirement and was included in its reliability rating.

- c. **Emergency Mode.** In the event of the loss of function of both evaporation units, the filtration unit can be used to process condensate from the condensate collection tank. Product water is routed to the holding and collection tanks and is analyzed for potability in essentially the same manner as during normal operation. Water storage and the emergency unit processing capacity is such that minimum subsistence levels for water will be obtained for a maximum period of 17 days. This time is considered sufficient to allow for the repair of failing units and/or receipt of water and equipment from resupply.

In addition to stored water, water available during the emergency conditions consists of 4.84 lb/man-day of recovered humidity condensate and 1.90 lb/man-day of Bosch reactor water. Water consumed (other than that contained in food) would be 7.65 lb for drinking and food rehydration plus 2.10 lb/man-day for electrolysis. Table 4.3-I shows the emergency water balance for 17 days. From this balance it can be seen that a total 205 lb of water is required for emergency storage. During the emergency, urine would be stored until the capacity of the urine and wash water collection tanks was exceeded. The urine would then be vented overboard.

Table 4.3-I. Emergency Water Balance

SOURCE OR USE	WATER CONSUMED, lb	WATER AVAILABLE, lb
Drinking and food preparation	520	
For electrolysis	143	
Recovered humidity condensate		329
From Bosch reactor		129
Emergency storage		205
	<hr/> 663	<hr/> 663

An additional emergency consideration involves the contamination of the emergency water storage supply. A sample port is provided on the emergency storage tank so that periodic bacteria checks can be made. If the emergency stores have been contaminated with bacteria, BAC will be added so that the final concentration is 1:100,000. At this concentration, the BAC cannot be detected by organoleptic tests. Tests on ingestion of water with BAC have been made on animal colonies at concentrations of 1:1,000 without cumulative toxic effects.

4.3.4 INTEGRATION. Integration of the water management subsystem within the life support system involves several subsystems.

4.3.4.1 Electric Power. The air evaporation units requires power for the recirculating fans. The prototype units are smaller than the units specified for flight and were considered to consume somewhat less power as follows:

	<u>Power, watts</u>	<u>Nominal Operating Time, hr/day</u>
Processing Unit No. 1	73	8
Processing Unit No. 2	73	20

In addition, an estimated 15 watts is required for instrumentation and control.

4.3.4.2 Thermal Requirements. Heat from the process heat fluid loop (DC-331) is used in the air evaporation units. In addition, the cooling fluid loop (FC-75 was initially employed) is used for heat rejection in the processing units, Table 4.3-II.

Heat lost from the air evaporation units to the cabin atmosphere is considered to be small.

Table 4.3-II. Estimated Heating and Cooling Requirements,
Water Management Subsystem

FLIGHT SUBSYSTEM	HEAT TO FLUID (Btu/hr)	TEMPERATURE OF FLUID (°F)	FLOW RATE OF FLUID (lb/hr)	NOMINAL OPERATING TIME (hr/day)
Heating				
Processing Unit 1	2385	---	---	16
Processing Unit 2	2385	---	---	6.5
Cooling				
Processing Unit 1	2525	---	---	16
Processing Unit 2	2525	---	---	6.5
<u>PROTOTYPE SUBSYSTEM</u>				
Heating				
Processing Unit 1	1932	345-385	20-50 (30)	20
Processing Unit 2	1417	345-385	20-50 (30)	8
Cooling				
Processing Unit 1	2248	34	250-350 (250)	20
Processing Unit 2	1657	70	250-350 (250)	8

4.3.4.3 Instrumentation and Control. For operation of the two air evaporation units, automatic control of feed rate and the air temperature downstream of the evaporator is considered mandatory.

In addition, the following parameters are to be monitored for operation according to processing requirements:

- a. Water conductivity.
- b. Water contamination.
- c. Pretreatment tank level.
- d. Water output rate.

The emergency filtration system requires control of the flow rate and collection tank pressurization.

4.3.4.4 Waste Disposal. Expended wicks and charcoal filters must be stored. Storage facilities that prevent escape of any undesirable odors are required. Urine residues amount to approximately 0.7 lb/day; wash water and condensate residues amount to approximately 0.035 to 0.1 lb/day.

4.3.4.5 Vacuum Source and Fluid Transport. A vacuum vent to the urine storage tank is provided to vent urine overboard in case of operation in the emergency mode. Fluid lines between the thermal control system for heating and cooling fluids are required. Water lines between various subsystems are required for collection, processing, and consumption. Tank pressurization lines and controls are vented.

4.3.4.6 Resupply. Charcoal filters, wick cartridges, and pretreatment chemicals will be replenished at the end of each 90-day resupply period. The filters of the emergency filtration unit will also be resupplied as used.

4.3.4.7 Initial Start-up Water Requirements. To achieve initial start-up of the water management recovery systems, a quantity of stored water is required. This quantity is dictated by recovery rates, use rates, and processing rates, (see Table 413-III).

On the third day, the water reclaimed from urine (processed on the second day) is passed to fresh storage for use after a check for impurities. Water reclaimed from humidity condensate and wash water requires holding an additional day for completion of a bacteria check. Four days is required to achieve steady-state operation.

4.4 WASTE MANAGEMENT

The waste management subsystem shall perform one or more of its three basic functions (collection and transport, treatment, and storage) for each of the following sources of recoverable and nonrecoverable wastes:

Personnel

Feces

Urine (collection and transport only)

Hygienic and grooming wastes

Food Management

Food leftovers

Food containers

Table 4.3-III. Start-up Water Requirements (lb for four men)

DAY	USE	COLLECT	PROCESS	HOLD	FRESH STORAGE	WATER DEFICIT
1	30.6D	19.6C				
	0.8E	13.2U				31.4
2	30.6D	19.6C	19.6C			
	0.8E	13.2U	13.2U			44.6
	13.2W	13.2W				
3	30.6D	19.6C	19.6C	19.36C	12.54UW	
	0.8E	13.2U	13.2U			32.1
	13.2W	13.2W	13.2W			
4	30.6D	19.6C	19.6C	19.36C	19.36C	
	0.8E	13.2U	13.2U		12.54UW	12.7
	13.2W	13.2W	13.2W	12.80W		
5	30.6D	19.6C	19.6C	19.36C	19.36C	
	0.8E	13.2U	13.2U		12.54UW	0
	13.2W	13.2W	13.2W	12.80W	12.80W	
Subtotal						120.8
Add 10%						12.0
						<u>132.8</u>

Note: D - H₂O for drinking and food preparation
E - H₂O for electrolysis makeup
W - Wash H₂O
C - Humidity condensate
U - Urine
UW - Urine water

Personal Hygiene

Chemical wipes

Paper wipes

Packaging materials

Cabin Refuse and Cleanup Materials

Oxygen Recovery

Carbon from CO₂ reduction

The dominant functions are the collection and transport, treatment, and storage of fecal matter. The waste management subsystem is required to provide these functions for the four-man crew in the mission as specified. Normal operation requires the processing of the following quantities of waste materials per day:

Feces	1.32 lb
Urine	13.6 lb (collection and transport only)
Refuse	2.10 lb
Carbon	2.45 lb

4.4.1 WASTE MANAGEMENT SUBSYSTEM. Figure 4.4-1 is a schematic diagram of the waste management subsystem.

4.4.1.1 Collection and Transport. Feces and urine collection in a zero-g condition is provided by ducting air from the cabin to the inlet of a blower through a semi-permeable bag for feces collection and a conventional aircraft relief tube for urine. Gas-liquid (solid) separation is provided by the semipermeable bag for feces collection and by the centrifugal separator for urine collection. Each in turn provides the basis for transport -- the bag as a manual transporter, and the centrifugal separator as a pump. Other recoverable waste liquids can be collected at the urinal, while the feces collector can be used for personal grooming waste collection. Objectionable odors released to the cabin are minimized by double charcoal filtration -- the first stage provided at the inlet to the blower, and the second stage supplied by the air conditioning charcoal filters. A urinal disinfectant circuit is provided.

4.4.1.2 Waste Treatment. Feces retained in the collection bags and other organic refuse is heat-vacuum dried in one of two drying chambers. Ventilation of the dryers is again provided by the zero-g air flow blower and circuit filters. A heated bacteria filter is provided in the space vacuum circuit.

4.4.1.3 Waste Storage. Storage is provided by four ambient containers vented to the air conditioning system and with sealable access lids.

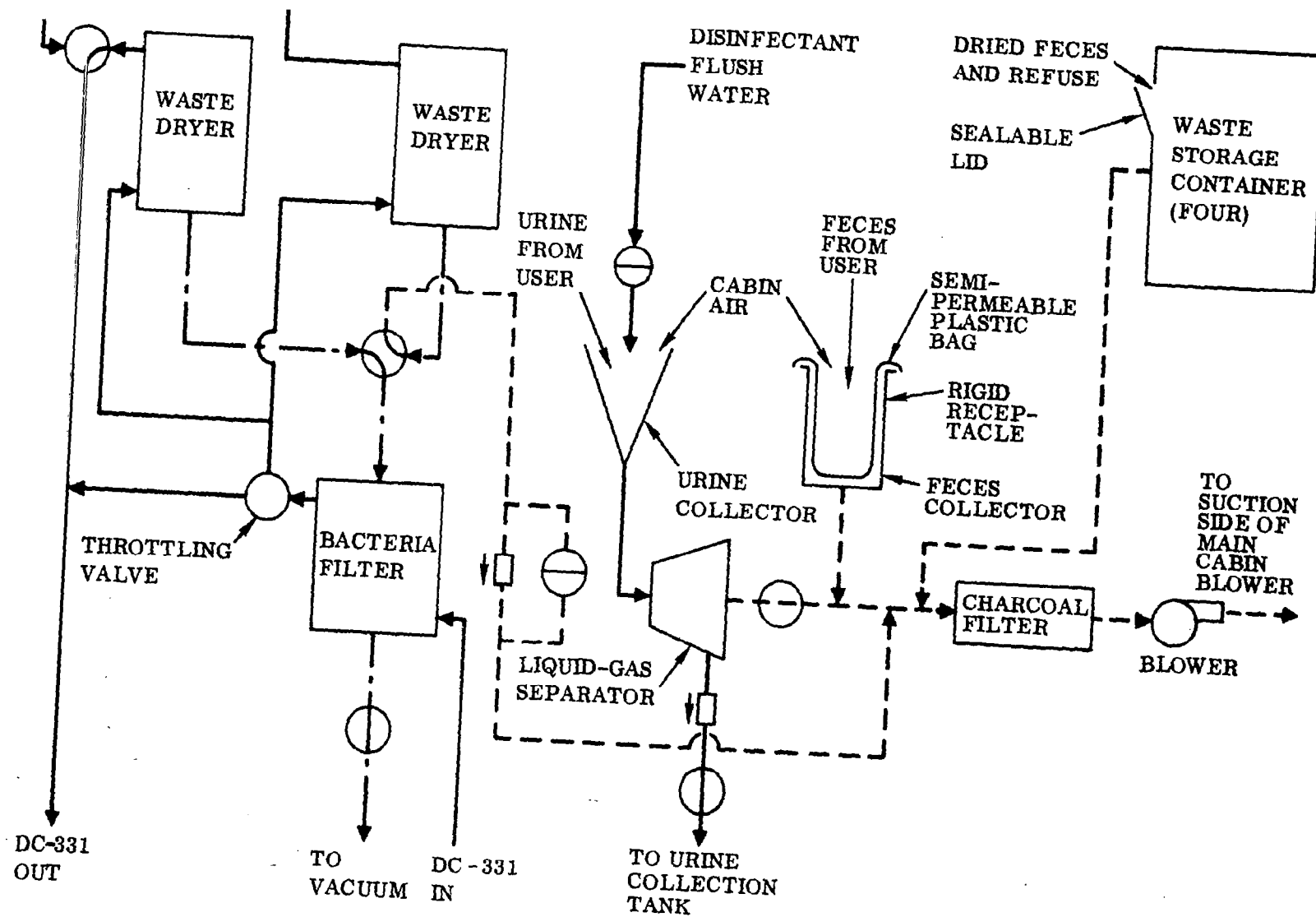


Figure 4.4.1. Waste Management Schematic

4.4.1.4 Emergency Provisions. Collection of feces during waste management collection shutdown is provided by plastic collection-storage bags employing manual manipulation and chemical treatment. Urine collection and transfer is accomplished with a manually manipulated rubber bladder.

4.4.2 ELECTRICAL POWER. Electrical power is required primarily for the motor-driven separator and air blower. For the 5- to 15-minute demands that total about one hour per day, 100 watts is considered adequate. About 1400 Btu/day (liquid thermal process heat) is required to support vacuum drying.

4.5 PERSONAL HYGIENE

The personal hygiene subsystem shall be compatible with both the psychological and physical well-being of the crew and be flexible enough to satisfy individual preferences as far as practicable. Materials and processes must be nontoxic, nonallergenic, and nonirritating.

Skin cleansing must remove salts, dead cells, rancid sebum, dirt, loose hair and other nondesirable materials.

Dental cleansing must be physically and chemically effective.

The equipment and procedures must be uncomplicated, generate a minimum of waste and minimum burden on water recovery, and fall within the water allotment of 5 lb per man day.

Organization and configuration of the subsystem must be such as to minimize the possibility of cabin contamination.

The materials and equipment required for personal hygiene are shown in Figure 4.5-1.

4.6 FOOD MANAGEMENT

The food management subsystem shall provide the food to support four crewmen for 90 days. It shall include the equipment for onboard storage, reconstitution, and serving of food and for waste packaging.

4.6.1 MENU AND FOOD QUALITY. Meal planning and menu determinations shall be based on 2,800 K cal per man-day in meals as nearly approaching the idealized home-cooked meal as possible. Desirable food states are determined as 80 percent dry (freeze-dried, dehydrated, dried) and 20 percent hydrated (breads, pastries, desserts, confection), of which approximately 40 percent can be frozen desserts.

NOTE: NO EMERGENCY CAPABILITY
90-DAY MISSION

TOTAL WT - 13 LB
TOTAL VOL - 576 IN.³
90-DAY MISSION, 4 MEN
LB/M-D LB IN.³

SPONGES (100)	0.07	6.3	450
BAC * (50% SOLUTION)	0.02	2.0	61
BAC * DISPENSER (FOR STORAGE TANK)	-	0.5	
FILTER, L/G SEP.			
SPONGE RINSING AND MOISTENING EQUIPMENT	-	2.0	30
BACK WASHING SPRONGE HOLDER	-	0.2	5
RACK AND DRYING CLIPS	-	2.0	30

PERSONAL HYGIENE SYSTEM
SUMMARY

TOTAL WT - 34 LB
TOTAL VOL - 0.8 FT³

ORAL HYGIENE SUBSYSTEM
TOTAL WT - 1.6 LB TOTAL VOL - 30 IN.³

90-DAY MISSION, 4 MEN	LB
BRUSHES - 2 PER MONTH (GUM MASSAGE TIP)	0.5
RACK	0.1
DENTIFRICE (EDIBLE, POSSIBLE CALCIUM SOURCE)	1.0

0.0036 LB/M-D
DENTIFRICE

3.2 LB/M-D WATER
0.02 LB/M-D BAC*

3.3 LB/M-D + 0.02 LB/M-D BAC*
125°F

0.20 LB/M-D WATER
VAPOR TO ATMOSPHERE
(CREW, SPONGE, WIPES, ETC)

3.1 LB/M-D DIRTY
WASH WATER

WATER RECOVERY
SUBSYSTEM

WATER HEATER
3.3 LB/M-D

210 - 372°F
35 LB/HR

HEAT
TRANSPORT
SUBSYSTEM

SHAVING, HAIR & NAIL CUTTING SUBSYSTEM
TOTAL WT - 1.114 LB TOTAL VOL - 20 IN.³

90-DAY MISSION, 4 MEN	LB
RAZOR, ELECTRIC (1)	0.75
EXTRA CUTTING HEAD (1)	0.013
DISPOSABLE COLLECTION BAGS FOR CUTTINGS (4)	0.026
RACK OR CLIP	0.2
SAFETY SCISSORS	0.125

PARTICULATE

MOIST WIPES

DISPOSABLE
BAGS
HAIR CLIPPINGS
& NAILS

"WIPES"
0.316 LB/M-D
MISC. MATERIALS
0.01 LB/M-D***

WASTE

90-DAY MISSION, 4 MEN
LB/M-D LB IN.³

"WIPES" (10 DAILY)**	0.03	11	576
TOWEL (1/MONTH)	-	6	250
RACK DISPENSER	-	1	50
DRYING CLIPS	-		

ALL OTHER PERSONAL HYGIENE
ACTIVITIES SUBSYSTEM

TOTAL WT - 18 LB
TOTAL VOL - 876 IN.³

- * BENZALKONIUM CHLORIDE
(ANTISEPTIC WITH DETERGENT PROPERTIES)
- ** IMPREGNATED WITH ANTISEPTIC, USED DRY OR MOIST
- *** MUCUS, SALIVA, EAR WAX, TEARS, SEMINAL FLUID

Figure 4.5-1. Personal Hygiene System Schematic

Dry components of the ration are required to be stable at room atmospheric conditions for at least one year. Federal food and drug requirements must be met or exceeded whenever antioxidants, preservatives, flavor enhancers, etc., are employed. Maximum use shall be made of freeze-dried precooked and natural-state foods.

Compressed dry foods such as cereal and fruit bars are recommended as applicable.

Packaging in plastic containers that serve for storage, reconstitution, serving, and disposal is recommended. The rehydration containers are required to be stable at 212° F for a period of three hours.

4.6.2 FOOD PREPARATION FACILITIES. The hot-water-dispenser controlling temperature shall be approximately 180° F. The dispenser shall be capable of dispensing 24 lb/day in 2-pound lots and of metering a given amount of water directly into the selected food container.

The cold water (40° F) dispenser shall be capable of metering selected quantities directly into the food container. Total daily draw is defined as 25 pounds, with draw lots of approximately one pound.

Connections shall be provided for bulk water draws for such items as the space suit biopack.

Two trays shall be configured to restrain food packets, provide thermal insulation for prepared foods and beverages, and organize the meal.

4.6.3 FOOD STORAGE. Specific storage requirements are defined for 100 days of food for four men. Meal organization is required to be such that individual crewmembers can select their own meals in the desired rotation. Packages are required to list the crewman's name, menu, calorie content, and order and the elapsed-time requirements for rehydration.

4.6.4 WEIGHT AND VOLUME. Estimated weights and volumes are as follows.

	<u>Weight (lb)</u>	<u>Volume (cu ft)</u>
Water Dispenser	10	0.5
Food (ambient storage)	770	52.0 (includes racks)
Food (frozen dessert)	90	3.0
Storage Rack	33	-
Trays	2	0.3

4.7 INSTRUMENTATION AND CONTROL

4.7.1 CLASSIFICATION OF INSTRUMENTATION AND CONTROL. Instrumentation and control is divided into two classifications.

- a. Spacecraft System. The spacecraft system is to include all internal instrumentation and controls to permit successful crew operation of the LSS in the test bed. It is to be a state-of-the-art flight-type system meeting the operational and design requirements of the LSS systems specifications.
- b. Ground Control System. The ground control system is to provide necessary information and controls to the ground test conductor to successfully permit safe manned and unmanned operation of the LSS in the test bed. Laboratory-type instruments for this purpose are to be used internally and externally.

4.7.2 SPACECRAFT SYSTEM

4.7.2.1 Purpose. The system shall permit controlled, safe, manned operation of the spacecraft. Crew control of the LSS shall be provided in a reliable, safe operation during the simulation of a spacecraft mission.

4.7.2.2 Functional Requirements. The system shall provide simple, reliable, primarily manual controls with automatic circuits used wherever practicable to reduce requirements for crew monitoring. Manual overrides are to be incorporated for increased system flexibility and reliability.

Information displays and alarms to assure crew safety, evaluate performance, and permit onboard troubleshooting of the LSS shall be provided.

Thermal and electrical overload cutoffs and switching functions to prevent self-destruction or fire hazard shall be provided.

4.7.2.3 Specific Functional Requirements. Specific functional requirements are identified and evaluated to permit proper selection of parameters to be monitored and to establish detail instrumentation systems requirements. (See Table 4.7-I.)

4.7.2.4 Man-Machine Relationship. The man-machine relationship is to be evaluated to optimize the probability of successful operation of the prototype LSS. Crew capability to evaluate data and control intermittent functions is to be favored over automatic controls or alarm systems. The following parameters are to be included in the considerations of the degree of automatic and manual actions provided for subsystem control circuits: allowable downtime; required crew reaction time; consequence of failure of control or alarm system; relative complexity of the candidate approaches; and ability of the crew to directly monitor the condition of the function.

Table 4.7-I. Functional Requirements

SYSTEM FUNCTIONAL REQUIREMENTS	PARAMETER OF INTEREST	FACTORS AFFECTING PARAMETER	PARAMETER CHARACTERISTICS				ALLOW- ABLE DOWN TIME	INSTRUMENTATION AND CONTROL REQUIREMENTS	
			NOMINAL AND DEVIATION	CREW SAFETY LIMITS	ACCURACY	RESPONSE TIME		SPACECRAFT	GROUND CONTROL
Atmospheric Composition Control	O ₂ Partial Pressure	1) Crew usage, 0.312 lb/hr 2) Atmospheric stores makeup 3) O ₂ regeneration, 7.5 lb/day 4) Leakage O ₂ , 10 lb/mo 5) Cabin volume, 4060 ft ³ 6) Cabin total pressure, 10 psia	160 mmHg 150-165 mm Hg	140-180 mm Hg (one-hour limit)	± 2 mm Hg	Slow	Approx. 28 hours (with no O ₂ added) Approx. 17 days (emergency consumption of atmos- pheric stores)	1) Sensor: polarographic and gas chromato- graphic information from ground control 2) Display: control panel 3) Control: manual 4) Alarm: O ₂ stores total usage at equipment	1) Sensor: provide sampling for GC analysis 2) Display: control panel 3) Control: manual (separate supply) 4) Alarm: to be 'determined'
	CO ₂ Partial Pressure	1) Crew outage, 0.387 lb/hr 2) Process removal of CO ₂ 3) Leakage to space 4) Oxidation and/or fire 5) Cabin volume, 4060 ft ³ 6) 3.8 mm Hg = 2.26 lb CO ₂	3.8 mm Hg 0-4.0 mm Hg	15.2 mm Hg (one- hour limit)	To be determined	Slow	Approx 17.5 hours (with no CO ₂ removal)	1) Sensor: pH of electro- lyte, gas chromato- graphic information 2) Display: control panel 3) Control: none 4) Alarm: to be deter- mined	1) Sensor: provide sampling for GC analysis 2) Display: control panel 3) Control: none 4) Alarm: to be determined
	Total Cabin Pressure	1) Leakage, 33.5 lb/mo 2) Atmospheric stores makeup 3) Cabin volume, 4060 ft ³ 4) Meteorite pene- tration or loss of integrity through vacuum interface 5) Normal operat- ing pressure, 10 psia	10 psia 10-15 psia	(Min O ₂ pp)	± 0.5 psi	Slow		1) Sensor: bourbon gage 2) Display: control pan- el 3) Control: makeup manual, excess manual 4) Alarm: excess N ₂ stores usage rate; excess cabin total pressure; monitor N ₂ stores rate and total usage	1) Sensor: Wallace and T. gage 2) Display: control panel 3) Control: external capability to pressurize or de- compress 4) Alarm: excess cabin pressure and low cabin pressure (approx. .9 psia)

4.7.2.5 Display and Alarm. Direct readout instruments to evaluate performance and facilitate fault isolation shall be provided. Critical parameters and parameters that identify an impending failure shall be instrumented as far as practicable to permit remote electrical readout or alarm. Alarms must be visual or audible and coded to permit identification of failure.

4.7.2.6 Reliability Design Criteria. The most desirable instrumentation and control system design is the one offering the greatest probability of successful operation of the prototype LSS. The following design criteria are to be used to maximize the initial instrumentation control system reliability.

- a. Use of off-the-shelf, proven, flight-type components that meet LSS environmental requirements.
- b. Standardization of components, functions, and subsystems to permit minimum spare parts requirements and maximum interchangeability.
- c. Systems simplicity that optimizes the man-machine relationship.
- d. Ruggedness and stability of components and functions.
- e. Ease of maintenance and prohibition of man-induced failures.
- f. Provision of redundancy through use of manual overrides, repair capability, and duplication of function.
- g. Consideration of failure modes and the probability of maximizing system reliability and eliminating secondary induced failures.

4.7.3 GROUND CONTROL. The ground control system shall permit controlled, safe, manned or unmanned operation of the LSS in the test bed. The system shall provide:

- a. Simple, reliable, external or override controls for unmanned operation.
- b. Information displays and alarms to the ground test conductor for evaluation of crew safety and systems performance.
- c. A sampling system to permit external laboratory analysis of the cabin atmosphere composition and processed water purity.
- d. Power distribution and control to the spacecraft simulator.
- e. Isolated ground power receptacles on board the spacecraft to permit use of portable test equipment, etc.
- f. Necessary information and controls for ground service functions; e.g., spacecraft radiator simulator unit, water supply, gas supply, vacuum service.
- g. Audible communication between test conductor, spacecraft crew, and chamber operating crew under all expected operating conditions.

The ground control system design is to be established by the same evaluation process detailed in paragraph 4.7.2.6. Reliable laboratory equipment is favored. The only special requirements are that on board components function if required under compression, and that they do not contain materials considered to be toxic hazards.

4.7.4 OPERATIONAL REQUIREMENTS

4.7.4.1 Configuration. The operational system requirements and design philosophy shall be reviewed to establish the instrumentation and control system design configuration.

A panel mounted integrally with each subsystem is to be used to control and to evaluate subsystem performance quantitatively to permit failure analysis and maintenance. Each panel is to be designed and fabricated by the subsystem vendor. This should permit maximum use of reliable, direct-reading, industrial-type instrumentation.

A centrally located composite display of all subsystem status and on/off electrical power control shall provide an instantaneous survey of the LSS status. Each subsystem status must be indicated by out-of-tolerance indicator lights for each critical subsystem parameter. All light indicators are normally off.

The ground control console shall provide necessary data display and controls to permit safe manned and unmanned operation of the test bed by the test conductor and ground control team. It shall consist of the following:

- a. Display of all subsystems.
- b. Electrical power analysis and control.
- c. Cabin atmosphere pressurization control and leak simulation.
- d. Gas sampling facility.
- e. Electronic heat load simulator controls.
- f. Critical system pressures.
- g. Critical system temperatures recorded on a multipoint recorder.
- h. Status-light activity on events recorders to provide a permanent record.

4.7.4.2 Failure Analysis. Component-by-component failure analyses shall be conducted on each subsystem as a backup to the functional analysis, as shown for the electrolytic unit, Table 4.7-II. The contents and organization of the failure and effects analysis are tailored to provide the following information.

Table 4.7-II. Water Electrolysis Failure and Effects Analysis

PART	FUNCTION	FAILURE	CONSEQUENCE OF FAILURE	DETECTION	CORRECTIVE ACTION	URGENCY REACTION	PROBABILITY OF FAILURE	CREW SAFETY	MISSION SUCCESS
No. 1, 2, 3 H ₂ cell check valves or No. 4, 5, 6 O ₂ cell check valves	Prevent back flow during cell shutdown. (2)	Open	If one cell is cooling off (shutdown) or same cell check valve fails, H ₂ may back-pressurize the membrane, pressurize the electrolyte, and cause electrolyte seepage, contaminating the O ₂ circuit.	Cell ΔP increase (H ₂ vs electrolyte) Filter Discoloration ⁽³⁾	Shut down unit. Repair check valve. Replace electrolyte absorbent filter. ⁽⁴⁾	Filters should be checked after each shutdown. (None)	10 ⁻¹ (1)	1	1
		Closed	H ₂ will build up pressure, rupture the membrane, force electrolyte into the O ₂ , and contaminate the O ₂ circuit.	H ₂ pressure increase Electrolyte pressure increase	Same	0 to 3 minutes	1	8	8
	Prevent back flow. (2)	Open	None	None	None		9	9	9
No. 7 H ₂ check valve or No. 8 O ₂ check valve		Closed	H ₂ /O ₂ will pass through the cell membrane, pressurize the electrolyte, and cause electrolyte contamination of the H ₂ /O ₂ circuit (rupture membrane).	H ₂ pressure increase O ₂ pressure increase	Shut down unit.	0 to 3 minutes	1	9	9
H ₂ & O ₂ circuit particulate filter	Remove solid particles. Absorb and neutralize electrolyte.	Open (rupture)	Does not remove particles or electrolyte carryover. Contamination of regulators, lines, and reactor catalyst. ⁽⁴⁾	Visual inspection of filter ⁽³⁾	Shut down unit. Replace filter.		1	3	3

NOTES: (1) This failure assumes that ΔP of O₂ during shutdown can cause sufficient system pressure differential to induce electrolyte seepage.

(2) A check valve requirement is not entirely obvious. Failure in a closed condition could cause permanent damage to cell.

(3) Use a dye in the electrolyte and provide visual inspection plate on filter inlet side. Provide a back plate to prevent rupture of filter diaphragm.

(4) Liquid absorbent (basic) neutralizer filter at outlet of each cell to minimize damage by electrolyte carryover.

- a. Function of component.
- b. Failure modes of component.
- c. Consequence of each failure mode (effect on subsystem and system).
- d. Method of detection.
- e. Corrective action.
- f. Urgency of reaction.
- g. Probability of failure -- a number between 1 and 100 as estimated by evaluator.
- h. Crew safety (a number between 0 and 100).
- i. Mission success (a number between 0 and 100).
- j. Remarks -- suggested testing, redesign, etc., that may decrease the probability of failure.

The failure and effects analysis is a tool that provides:

- a. An organized approach for inspection of the total system.
- b. A record of the operation of each component and its total performance in relation to the overall system performance.
- c. Detailed identification of measurable parameters and the relative criticality of each.
- d. A focus on inherent problem areas for closer evaluation.

4.7.4.3 Vendor Coordination. Shortly after award of contracts, the preliminary failure analysis and instrumentation and control requirements shall be forwarded to each subsystem vendor for review and comment.

During subsystems predesign review, all subsystem schematics, electrical circuit schematics, failure analyses, panel layouts, parts lists, and instrumentation and control analyses shall be reviewed to determine the adequacy of the proposed instrumentation and control system.

During final design review, the instrumentation and control system analysis, subsystem failure analysis, panel displays, parts lists (not previously approved), system schematics, electrical circuit schematics, maintenance analysis, and drawings shall be reviewed and the instrumentation and control requirements finalized between Convair and vendors.

4.7.5 GAS ANALYSIS. The analysis of cabin atmosphere and subsystem equipment process gases will provide evaluation of system performance; and on-line decision-making for test control by both equipment operators and the test monitors.

Essentially all LSS testing involving O₂ recovery (water electrolysis, CO₂ concentration, and CO₂ reduction), catalytic burner operation, or test bed atmospheric composition analysis, require on-line gas detection and analysis. All system-level testing require on-line measurements in each of the following categories:

- a. Cabin atmosphere composition analysis.
- b. Subsystem process gas measurements.
- c. Trace contaminant detection and analysis of both atmospheric and process gases.

Gas analyses shall be accomplished with commercial laboratory-type equipment.

Gas sampling circuits shall be provided to circulate process loop samples for external laboratory analysis. Each network shall remain isolated; manifolding could give rise to cross-contamination problems, either real or imaginary. The ground control console shall provide a gas-sampling collection station adaptable to continuous sampling or extraction by standard medical syringe for transport to analytical equipment.

The sources, analytical requirements, time constraints, and proposed detection methods to support the LSS development and test programs are shown in Table 4.7-III.

Table 4.7-III. Gas Analysis Requirement

SOURCE	CONSTITUENTS AND CONCENTRATIONS	FREQUENCY OF TESTS	DETECTION METHOD
Cabin Atmosphere Living and Laboratory	O ₂ ~ 160 mm Hg N ₂ ~ 355 mm Hg CO ₂ ~ 3.8 mm Hg H ₂ < 30 mm Hg CH ₄ < 30 mm Hg CO < 30 ppm NH ₃ < H ₂ S < Trace contaminants	1 - 4 hours ↓ Daily	GC ↓ GC → MS IR
Catalytic Burner In and Out	CO < 30 ppm H ₂ < 10 mm Hg CH ₂ < 10 mm Hg Trace contaminants	Daily ↓	GC ↓ GC → MS IR
Charcoal Filter Living and Laboratory	Trace contaminants	Weekly	GC → MS IR
CO ₂ Concentration Unit CO ₂ Accumulator	N ₂ 7.6 mm Hg	Hourly	GC
Process Air Out	CO ₂ 3.8 mm Hg	4 hours	GC
CO ₂ Reduction Recycle Gases	H ₂ ~ CO ~ CO ₂ ~ CH ₄ ~ H ₂ O @ 55° F	30 minutes 10 minutes ↓	GC ↓
Water Electrolysis Purity of O ₂	H ₂ < 0.76 mm Hg H ₂ O (moisture-free) Trace contaminants	Infrequent ↓	MS MS GC-MS (IR) O ₂ - 99.7% Pure
Water Electrolysis Purity of H ₂	H ₂ O (moisture-free) O ₂ < 0.76 mm Hg Trace contaminants	Infrequent ↓	MS MS GC-MS (IR) H ₂ - 99% Pure

SECTION 5

PROCUREMENT SPECIFICATIONS

Most of the items requiring specific development for the LSS and representing existing product lines within industry were required to be subcontracted. Definitions of the equipment items and the contractor/subcontractor responsibilities within the development program were spelled out in an integrated procurement specification. The specification defined the goals of the eventual flight equipment as well as the specific requirements of the prototype configuration. It included requirements and/or definitions of:

- a. Design
- b. Performance
- c. Environments
- d. Reliability
- e. Program Planning
- f. Progress Review
- g. Testing and Acceptance Criteria
- h. Documentation

The procurement specification provided the basis for the competitive bid procurement employed for each item. The single-document approach was adopted, to increase the assurance that communications between customer, contractor, and subcontractor would be accurate and current. The specifications were updated by contractor-subcontractor action and customer approval as significant changes were dictated by the changing level of information being made available within the development program.

5.1 SUMMARY OF A TYPICAL SPECIFICATION

Although each specification was tailored to fit the item under definition, it is possible to generalize and thus summarize a typical format. Each specification contained seven numbered sections and a prefixed section giving a history of all changes recorded against the specification.

5.1.1 SECTION 1 -- SCOPE. This section identifies the units under procurement by title and number, defines the terminology, outlines the use to which the items will be put, and presents the general guidelines to be followed with respect to weight, design concepts, reliability, size, performance, power, environment, thermal characteristics, maintainability, and safety.

5.1.2 SECTION 2 -- APPLICABLE DOCUMENTS. This section lists references and applicable specifications.

5.1.3 SECTION 3 -- REQUIREMENTS. This section lists guidelines for the use of standard parts and interconnects, selection of materials with respect to criticality, deterioration resistances (including materials outgassing and/or contamination of the spacecraft cabin), and selection of electrical parts with respect to signal and radio noise-generating characteristics. Finishes, use of dissimilar metals, workmanship and bonding requirements are outlined.

Maintenance and maintenance guidelines are defined, and specific allowable maintenance times are detailed. Allowable maintenance times varied according to unit complexity and the criticality of the function to the overall system. Allowable preventive maintenance times ranged from 0.5 hour to 2 hours with average corrective maintenance times from 1 to 6 hours and maximum corrective maintenance times from 3 to 24 hours.

The general configuration and unit functions are outlined, control types are noted for each major operating parameter, and the weight-power penalty are values defined as:

Power penalty	290 lb/kw
Heat rejection penalty	0.01 lb/Btu/hr (sensible)
	28 lb/lb H ₂ O/hr (latent)

The prototype life requirements are defined, and the environmental and stress conditions are given.

The specific performance requirements are stated, including processing rates, product quality, process support inputs available, duty cycle, instrumentation and controls, and reliability. Critical operating conditions are defined.

5.1.4 SECTION 4 -- QUALITY ASSURANCE PROVISIONS. This section outlines the acceptance test and inspection requirements including the test durations, measurements to be taken, conditions of test, and types of tests (including proof pressure, leakage, performance, and maintenance). Special attention was given to assure that all operating functions required for a 100-day run, including servicing and maintenance, would be demonstrated at least once during the tests. In addition, sufficient cycling and steady-state run time was specified to provide assurance that early failures would be detected and representative performance values would be produced. Disassembly inspection following the tests was specified to provide a further check on the potential for early failure. To provide further detail and a high assurance that requirements were being understood and translated into test, the subcontractor was required to submit a detail test plan for contractor approval prior to initiation of the Source Acceptance Inspection (SAI) tests.

5.1.5 SECTION 5 -- PHILOSOPHY AND CRITERIA. This section presents an appeal to the subcontractor to assume responsibility for communicating potential or observed problems concerning the contractor's definition of requirements.

5.1.6 SECTION 6 -- DOCUMENTATION. This section defines the documentation to be prepared and the analyses to be performed during the subcontractor's development program. It covers:

- a. Drawings
- b. Instruction Books
- c. Modification Log
- d. Analyses (documented)
 - 1. Prototype vs. Flight Article Comparison
 - 2. Failure Mode and Effects
 - 3. Maintainability
 - 4. Reliability
 - 5. Instrumentation
- e. Test Procedure and Test Report
- f. Materials Evaluation
- g. Design Concept and Quality Assurance Program Plan
- h. Storage and Shipping Instructions
- i. Spares List (Flight and Prototype)

5.2 SUMMARY OF SPECIFIC REQUIREMENTS

Each procurement specification followed the general pattern summarized in the foregoing paragraph. The major requirements peculiar to each development item are summarized below.

5.2.1 CO₂ CONCENTRATION UNIT. (Specification 64-02004C)

5.2.1.1 General Configuration

- a. Auxiliary blowers as required.
- b. Water adsorbent beds.
- c. CO₂ adsorbent beds (synthetic zeolite).
- d. CO₂ adsorbent canister purge system.

- e. Thermal and vacuum desorption system.
- f. Automatic bed selection valve cycling system, including timers and controls.
- g. CO₂ storage or accumulator tank.

5.2.1.2 Operational Characteristics

- a. Prototype life \geq 250 hours.
- b. Allowable downtime (flight requirements).
 - 1. Reliability = 0.994.
 - 2. Availability = 0.99.
 - 3. Preventive Maintenance = 2 hours maximum.
 - 4. Corrective Maintenance = 3 hours average, 12 hours maximum.
- c. Manual operation capability to be provided for single-bed operation.

5.2.1.3 Performance

- a. At least 9.28 pounds of CO₂ per day.
- b. CO₂ partial pressure 3.8 mm Hg.
- c. Automatic operation.
- d. No more than 0.05 lb/day transferred to CO₂ accumulator from absorbent canister.

5.2.1.4 Acceptance Tests

- a. Three full-scale on-off cycles.
- b. Nine test runs varying as defined by one or more parameters.
 - 1. Inlet air temperature.
 - 2. Inlet air pressure.
 - 3. Inlet CO₂ partial pressure.
 - 4. Inlet air dew point.
 - 5. Test duration.
 - 6. Desorption mode.
- c. Test measurements covering at least the following.
 - 1. Inlet-outlet CO₂ concentration.
 - 2. O₂ and H₂ concentration in CO₂ accumulator.

3. Total power.
4. Bed temperatures and pressures.
5. CO₂ accumulator pressure.
6. Air flow.
7. Moisture content of absorbing bed inlet air.
8. All measurements to provide total heat balances and transport loop characteristics.

5.2.2 CO₂ REDUCTION UNIT. (Specification 64-02003C)

5.2.2.1 General Configuration

- a. Bosch reactor.
- b. Regenerative heat exchanger.
- c. Condenser.
- d. Condensate separator and water delivery components.
- e. Recycle gas blower.
- f. Carbon collection and removal assembly and facilities.
- g. All controls, valves, and sensors required for unit operation.
- h. Sabatier reactor as alternate mode for emergency backup (4 H₂ + CO₂ \longrightarrow CH₄ + 2 H₂O).

5.2.2.2 Operational Characteristics

- a. Prototype life \geq 250 hours.
- b. Allowable downtime (flight requirements).
 1. Reliability = 0.96.
 2. Availability = 0.99.
 3. Preventive maintenance = 2 hours maximum.
 4. Corrective maintenance = 6 hours average, 24 hours maximum.
- c. Switching from primary mode (Bosch) to secondary mode (Sabatier) to be manually accomplished with minimum compromise of basic Bosch function.

5.2.2.3 Performance

- a. 9.28 lb/day CO₂ (CO₂ + 2 H₂ \longrightarrow 2 H₂O + C).

- b. CO₂ purity (air contamination) not to exceed 0.1 lb/day.
- c. Product water to be available for transport at 10 psig.
- d. Coolant available = 250 lb/hr at 32 ± 2° F and 800 lb/hr at 100° F.
- e. Process heat available at 375° F.
- f. Flow control required for inlet CO₂ and H₂.

5.2.2.4 Acceptance Tests

- a. Three full-scale starts and shutdowns, plus cyclic operation in eight days continuous run with at least 18 hours accumulated steady-state.
- b. Test Measurements
 - 1. Fluid flows and pressures.
 - 2. Fluid and reaction temperatures.
 - 3. Gas concentrations.

5.2.3 WATER ELECTROLYSIS UNIT (Specification 64-02005B)

5.2.3.1 General Configuration

- a. Several (3-6) identical electrolysis modules arranged for easy disconnect and replacement.
- b. All electrical and fluid interconnects located on one surface.
- c. Terminals for each cell of each module to be accessible for electrical measurements and/or shorting.

5.2.3.2 Operational Characteristics

- a. Prototype life ≥ 250 hours.
- b. Allowable downtime (flight requirement).
 - 1. Reliability = 0.99.
 - 2. Availability = 0.996.
 - 3. Preventive maintenance = 1 hour.
 - 4. Corrective maintenance = 3 hours average, 12 hours maximum.
- c. Automatic controls to be provided as necessary to preclude damage by interruption of coolant or water supply.

5.2.3.3 Performance

- a. Input water to be better than:
 1. pH = 6-8.
 2. Conductivity = 100 micromhos.
 3. Total solids = 100 ppm.
 4. Ammonia = 20 ppm.
 5. Chloride = 20 ppm.
 6. Sulfate = 20 ppm.
 7. Urea = 20 ppm.
- b. To perform without malfunction with input voltage 24-32 vdc.
- c. To produce at least 8.0 lb/day of O_2 and 1.0 lb/day H_2 delivered at 5-10 psig for 28-30 vdc input. Gases to contain no entrained liquid and be at less than 70°F.
- d. O_2 purity ≥ 99.7 percent (Volume) with $H_2 = 0.1$ percent (Volume).
- e. H_2 purity ≥ 99 percent (Volume).
- f. Coolant flow available @ 100 lb/hr and $32 \pm 2^\circ F$.
- g. Coolant circuit pressure drop ≤ 7 psi.

5.2.3.4 Acceptance Tests

- a. Total test time not less than 18 hours.
- b. Three on-off cycles, with a minimum of 4 hours continuous operation at equilibrium temperature following third start.
- c. All cyclic operations included in an 8-day run to be included in test.
- d. Off-design runs.
 1. Two overvoltage conditions: 3v and 2v above voltage to produce 8 lb/day.
 2. Coolant flow off, water feed off.
- e. Test measurements.
 1. Mass balance (quantitative)
 - (a) Water electrolyzed.
 - (b) O_2 produced.
 - (c) H_2 produced.

2. Energy balance.

- (a) Duration of test.
- (b) Electrical input.
- (c) Feed water and product gases pressure and temperature.
- (d) Coolant flow and temperatures (inlet and outlet).
- (e) Accessory power.
- (f) Heat to surroundings.

3. Product gas quality.

5.2.4 HIGH-TEMPERATURE CATALYTIC BURNER (Specification 64-02023B)

5.2.4.1 General Configuration

- a. Regenerative heat exchanger.
- b. Heating element.
- c. Temperature controller.
- d. Oxidizing catalyst and acid gas absorbing bed of Li_2CO_3 (10 percent by weight of oxidizing catalyst).

5.2.4.2 Operational Characteristics

- a. Prototype life ≥ 750 hours.
- b. Allowable downtime.
 - 1. Reliability = 0.995.
 - 2. Availability = 0.997.
 - 3. Preventive maintenance = 0.5 hour.
 - 4. Corrective maintenance = 2 hours average, 6 hours maximum.
- c. Provide warning for abnormal temperatures and automatic shutdown for heater overtemperature.

5.2.4.3 Performance

- a. Unit to be capable of completely oxidizing CO , H_2 , and other hydrocarbon contaminants, except that lower-molecular-weight hydrocarbons such as methane and ethane shall be oxidized at least 50 percent at the 700°F operating temperature.

- b. To process 8.25 lb/hour (cabin air) to 700°F with use of the regenerative heat exchanger and electrical heater and automatically limit catalyst temperature to 800°F maximum.
- c. Residence time for an air flow of 4.95 lb/hr (normal) to be at least 1.0 second.

5.2.4.4 Acceptance Testing

- a. Ten full-scale on-off cycles with heater elements reaching stabilization temperatures.
- b. Functional tests to be run at 10 psia with O₂ partial pressures of 100 mm Hg and 160 mm Hg.
 - 1. 1.0 lb/hr with heater holding 700 - 800°F with flow stepwise advanced to 8.25 lb/hr and held until stabilized, three cycles.
 - 2. Oxidizing efficiency established for normal flow of 4.95 lb/hr and off-design flows of 6.60 and 8.25 lb/hr with inlet contaminants at each condition:

CO = 1200 ppm

CO = 10 ppm

CH₄ = 1 percent

CH₄ = 200 ppm

H₂ = 1 percent

H₂ = 200 ppm

Conditions also to be run at 14.7 psia.

- c. Test measurements.
 - 1. Heat exchanger effectiveness.
 - 2. Power consumption.
 - 3. System operating temperature.
 - 4. System pressure and pressure drop.
 - 5. Air flow rate.
 - 6. Inlet and outlet contamination concentrations.
 - 7. Oxidation efficiencies.
 - 8. Surface temperature distribution.

5.2.5 WASTE HEAT AIR EVAPORATION WATER RECOVERY UNIT (Specification 64-02018B)

5.2.5.1 General Configuration

- a. Evaporator.

- b. Filters.
- c. Pretreatment tank.
- d. Metering circuit.
- e. Blower.
- f. Water separator.
- g. Heat exchanger and condenser.

5.2.5.2 Operational Characteristics

- a. Prototype life \geq 500 hours.
- b. Allowable downtime (flight requirement).
 - 1. Reliability = 0.992.
 - 2. Availability = 0.995.
 - 3. Preventive maintenance = 2 hours.
 - 4. Corrective maintenance = 3 hours average, 10 hours maximum.
- c. Automatic controls.
 - 1. Feed-metering control.
 - 2. Evaporator temperature.
 - 3. Condensate pump rate (if required).
- d. Liquid quantity indicator required for pretreatment (supply) tank.
- e. Manual waste residual removal includes cabin contaminant protection.

5.2.5.3 Performance

- a. Process rate \geq 1.25 lb/hr.
- b. Process heat available = 22.5 lb/hr at 345-385° F; heat exchanger pressure drop not to exceed 10 psi.
- c. Coolant available = 350-400 lb/hr at 72-83° F; heat exchanger pressure drop not to exceed 5 psi.
- d. Pretreatment manual, positive, and accurate for each 13.2 pounds of urine, 13.2 pounds of waste wash water, and 19.6 pounds of condensate.
- e. Product water quality as defined in system specification.
- f. Gas leakage rate not to exceed 40 cc/day.
- g. Evaporator flooding to be prevented by unit design.

5.2.5.4 Acceptance Tests

- a. Ten full-scale on-off cycles.
- b. Functional tests.
 - 1. 20-hour urine run.
 - 2. 4-hour wash-water run.
 - 3. 4-hour condensate run.
 - 4. 1-hour urine run at 1.0 lb/hr.
 - 5. Demonstration of residual removal, liquid-gas separation, pretreatment dispenser, and automatic control required.
- c. Test measurements.
 - 1. Water flow rate, inlet and product.
 - 2. Electrical power.
 - 3. Total heat balance parameters.
 - 4. Operating pressures.
 - 5. Product water quality.

5.2.6 FILTRATION WATER RECOVERY UNIT (Specification 64-02009B)

5.2.6.1 General Configuration

- a. Activated carbon bed.
- b. Ion-exchange resin bed.
- c. Bacteria filter.
- d. Pump.

5.2.6.2 Operational Characteristics

- a. Prototype life ≥ 172 hours.
- b. Allowable downtime (flight requirement).
 - 1. Reliability = 0.999.
 - 2. Availability = 0.996.
 - 3. Preventive maintenance = 2 hours.
 - 4. Corrective maintenance = 2 hours average, 4 hours maximum.

5.2.6.3 Performance

- a. Purify condensate at rate of 1.23 lb/hr.
- b. Canister capacity = 17 days.

5.2.6.4 Acceptance Tests

- a. Ten on-off cycles.
- b. Functional tests.
 - 1. Operate on distilled water to demonstrate purity of canisters.
 - 2. Operate on actual condensate for 16 hours.
 - 3. Replacement of canisters demonstrated.
- c. Test measurements.
 - 1. Water flow rates.
 - 2. Recovery efficiency.
 - 3. Product water quality.

5.2.7 WASTE MANAGEMENT SYSTEM (Specification 64-02006C)

5.2.7.1 General Configuration

- a. Blower.
- b. Odor control filter.
- c. Feces collection stool.
- d. Disposable collection sacks (if required).
- e. Vacuum drying unit (thermal augmentation).
- f. Bacterial filters.
- g. Urine collection and transfer device (liquid/gas separator).
- h. Storage containers (ambient).
- i. Separate independent emergency facilities for four men for 17 days.

5.2.7.2 Operational Characteristics

- a. Prototype life \geq 2500 hours dryer operation with 400 collection cycles.
- b. Allowable downtime (flight requirement).
 - 1. Reliability = 0.995.
 - 2. Availability = 0.992.

3. Preventive maintenance = 2 hours.
4. Corrective maintenance = 1 hour average, 6 hours maximum.
- c. Transfer of feces from collector to dryer to storage is manual. All controls are manual. Urine collection and transport is mechanical.

5.2.7.3 Performance

- a. Process capacity.
 1. Feces = 1.32 lb/day (average).
 2. Refuse = 2.1 lb/day (0.1 ft³ volume).
 3. Urine = 16.5 lb/day maximum @ 5 psig and 240 lb/hr.
- b. Zero-g operation accomplished by air flow.
- c. Overboard air loss minimized by optimization of the volume and number of dryers.
- d. Unit must handle diarrhetic feces and vomitus.
- e. Process heat available at 250-375° F with flow rates of 30-60 lb/hr.

5.2.7.4 Source Acceptance Tests

- a. Five full-scale on-off cycles for dryers and ten for urine collection circuit.
- b. Functional tests (performed in a non-airtight enclosure and operated to simulate a five-day mission for four men, with demonstration).
 1. Odor control at collection, drying, and storage.
 2. Urine collection and transport capability.
 3. 95 percent removal of fecal water.
 4. Effectiveness of the treatment of waste food and feces.
 5. Liquid/gas separator effectiveness.
- c. Test measurements.
 1. Collector airflow.
 2. Airflow circuit pressure drop.
 3. System power.
 4. Water content of drying feces with respect to time.
 5. Odor filter effectiveness with time (life).
 6. Presence of bacteria downstream of filter.
 7. Pressure and temperature history of vacuum dryer.

5.2.8 PERSONAL HYGIENE. The major operating components of the personal hygiene subsystem are the wash water heater and the liquid/gas separator. The former was obtained under Specification 64-02014 as a duplicate of the food water heater. The latter was obtained under Specification 64-02006 as a duplicate of the urine liquid/gas separator.

5.2.9 FOOD MANAGEMENT (Specification 64-02014B)

5.2.9.1 General Configuration

- a. Food preparation console, including hot- and cold-water metering dispensers.
- b. Food serving trays (two) and other special utensils required for food preparation, ingestion, and handling.
- c. Packaged food and beverages, including dry and hydrated foods (10 days, four men).
- d. Food storage racks (100 days, four men) with canisters for only the 10-day requirement.

5.2.9.2 Operational Characteristics

- a. Prototype life ≥ 500 hours for operating equipment and one year for stored food.
- b. Allowable downtime (flight requirement).
 - 1. Reliability = 0.999.
 - 2. Availability = 0.98.
 - 3. Preventive maintenance = 0.5 hour.
 - 4. Corrective maintenance = 1 hour average, 3 hours maximum.
- c. Food reconstitution requires only addition of manually selected metered water into separate food item laminated transparent plastic storage-preparation-consumption packages.

5.2.9.3 Performance

- a. Food packaging materials to remain stable at 180° F for at least 1 hour.
- b. Packaging will permit contents reconstitution and ingestion at zero-g.
- c. Food nutritional value of 2800 K cal/man-day; 60 percent carbohydrate, 15 percent protein, 25 percent fat; purity at least to meet FDA requirements; provide high degree of crew acceptance.
- d. Food water heater.
 - 1. Process heat available at 210-372° F for 35 and 50 lb/hr respectively at 50 psig.

2. Provide water at $175 \pm 5^{\circ}\text{F}$ for two meals repeatable at intervals of two hours from an input supply available at 4 psig and 70°F .
3. Dispenser metering controls to be commensurate with reconstitution quantities.

e. Food water chiller.

1. Coolant available at $30\text{--}34^{\circ}\text{F}$ for 100 lb/hr at 65 ± 5 psig.
2. Provide water at $32\text{--}45^{\circ}\text{F}$ for the meal preparation cycle.
3. Dispenser metering controls to be commensurate with reconstitution quantities.

5.2.9.4 Source Acceptance Tests

a. Food and beverage packaging.

1. Accepts water without spillage.
2. Retains contents during hydration.
3. Zero-g feeding mechanism is adequate.
4. Imparts no flavor to contents.
5. Labeled correctly.

b. Food.

1. Is palatable, without off-flavors, and has a high satiety value.
2. Rehydrates satisfactorily and according to instructions.
3. Hydrated food produces no crumbs to cabin.

c. Food handling equipment.

1. Rack permits easy removal of meals and individual packages.
2. Retains and protects food adequately.
3. Tray keeps food at adequate temperatures and retains foods during preparation and meal consumption.

d. Water supply unit.

1. Easy to operate; does not leak.
2. Meters accurately within ± 0.5 ounce of selected value.
3. Dispenser penetrates food containers easily and efficiently.
4. Does not impart taste or impurities to water.
5. Safety devices must perform as required.

e. Test measurements as determined by test plan.

5.2.10 CABIN AIR WATER SEPARATOR (Specification 64-02024C)

- a. General configuration (not specified).
- b. Operational characteristics.
 - 1. Prototype life ≥ 500 hours.
 - 2. Allowable downtime (flight requirement).
 - (a) Reliability = 0.9995.
 - (b) Availability = 0.997.
 - (c) Preventive maintenance = 0.5 hour.
 - (d) Corrective maintenance = 1 hour average, 3 hours maximum.
- c. Performance.
 - 1. Air flow saturated; entrained moisture at 34-42°F with flows in the design range of 300-900 lb/hr for ambient pressures of 10 and 15 psia.
 - 2. Maximum flow range of 450-1320 lb/hr at 15 psia.
 - 3. Entrained moisture varies from 0.4 to 4.0 lb/hr.
 - 4. 95 percent entrained water removal for all flow ranges; water delivered at above 5.0 psig.
- d. Source acceptance tests.
 - 1. Three on-off cycles.
 - 2. Functional tests at 12 designated air flows ranging from 300 to 1320 lb/hr at specified water contents ranging from 0.4 to 4.0 lb/hr. Half the tests to be conducted at an ambient of 14.7 psia and half at 10 psia. Total test time not less than 18 hours.
 - 3. Test measurements.
 - (a) Air flow.
 - (b) Air pressure (in-out).
 - (c) Inlet temperature.
 - (d) Entrained water (air stream in and out).
 - (e) Product water quantity.
 - (f) Air velocity.

5.2.11 TEST SUPPORT EQUIPMENT. Equipment required to support the operation of the primary system was essentially that performing functions to be provided by the flight spacecraft system or the space environment. Such supporting equipments were not candidates for a flight system but rather simulations of functions supporting a flight system. These nonflight items were either procured by simplified specification or directly supplied by the contractor as part of the integrating task. Specifications did not include requirements for study tasks, program controls, and extensive documentation. For the most part, such requirements were assumed by the contractor under existing program procedures.

5.2.11.1 Spacecraft Cabin Test Bed (Specification 64-02002B)

- a. General configuration (specification control drawing 64-02001).
 - 1. Main compartment with two levels.
 - 2. Airlock compartment.
 - 3. Viewing ports, hatches, flanges, and stairway.
 - b. General requirements.
 - 1. Material -- low carbon steel.
 - 2. Internal Pressure = 0-15 psia (each compartment and airlock independently).
 - 3. ASME Unfired Pressure Vessel Code is a guide.
 - 4. Loads on individual brackets or mounts not to exceed 250 pounds.
 - c. Source acceptance tests.
 - 1. High-pressure structural test (per code).
 - 2. Airlock posture pressure leakage test = maximum allowable average hourly pressure drop of 0.02 psi for 6 hours with initial pressure of 20 psia and main compartment vented to ambient.
 - 3. Negative pressure leakage tests. Independent tests for compartments and airlock to demonstrate that the average hourly leak-up rates are no more than 0.00215 psi for main compartments and 0.02 psi for the airlock over a period of 6 hours with an initial pressure of 5 psia.
 - 4. High vacuum structural test. Each compartment to independently withstand, without deformation, full blank-off vacuum of the contractor's mechanical pumps.
 - d. Responsibility for modifications to meet specifications rests with the subcontractor.
- 5.2.11.2 Fluid Cooling and Pumping Unit (Specification 64-02013B)
- a. General configuration.

1. Good commercial practices.
 2. Filters, expansion controllers, relief valves employed for safe operation and circuit protection.
 3. Fluid reservoir to include means of system air bleed.
- b. Performance.
1. Manually adjusted, automatically controlled flow rates from 400 to 2500 lb/hr with ± 3 percent accuracy for ± 10 psig line pressure changes.
 2. Outlet temperature automatic control at $32 \pm 2^\circ\text{F}$ for flows of 400 to 1500 lb/hr with inlet from 50 to 150°F .
- c. Source acceptance tests.
1. Five hours each at 1500, 2000, and 2500 lb/hr at inlets of 50 to 150°F , with outlet maintained at $32 \pm 2^\circ\text{F}$ at least at the design point of 1500 lb/hr.
 2. Safety devices to be demonstrated.
 3. Test measurements.
 - (a) Fluid flow.
 - (b) Inlet and outlet temperatures.
 - (c) Unit pumping characteristics.

5.2.11.3 Fluid Heating and Pumping Unit (Specification 64-02011B)

- a. General configuration.
1. Electrical fluid heater.
 2. Positive-displacement direct-motor-drive pumps.
 3. Fluid expansion controller.
 4. Filter outlet.
 5. Reservoir (25 pounds of fluid) with system air bleed.
 6. Manually adjustable automatic flow control.
- b. Performance.
1. Flow control accuracy of ± 2 percent at any selected point in the range of 0 to 750 lb/hr with line-pressure changes of ± 10 psig.
 2. Temperature control accuracy of $\pm 10^\circ\text{F}$ at 390°F for flows up to 750 lb/hr with inlet temperatures ranging from 140 to 300°F .
 3. Pressure rise requirement = 40 psi.

c. Source acceptance tests.

1. Ten full-scale on-off cycles.
2. Functional tests to include modulation of inlet temperatures from 140 to 300°F for each of three flow rates (100, 300, and 750 lb/hr) with outlet temperature control required at $390 \pm 10^\circ\text{F}$ except for 750 lb/hr, where only the 300°F inlet case will apply.
3. Safety devices to be demonstrated for:
 - (a) Fluid flow interruption.
 - (b) Unit cooling failure.
 - (c) Proper sequence of fluid-flow heater power during start-up.
4. Test measurements.
 - (a) Fluid flow.
 - (b) Inlet - outlet temperatures.
 - (c) Unit pumping characteristics.

5.2.11.4 Instrumentation and Controls. Instrumentation and controls other than those supplied integrally with subcontractor equipment were supplied by the contractor as part of the integrating task and were not covered by procurement specifications. The subsystem specification as followed by the contractor is covered in Specification 64-26214, with the detailed descriptions covered in Specification 64-26140, "Life Support System Instrumentation."

SECTION 6

FINAL DESIGN DESCRIPTION

During the functional tests conducted in January through March 1965, it became evident that some system modifications would be required to achieve desired performance and operational characteristics. System improvements and evaluation testing were authorized by contract change notice (CCN) No. 5, accomplished April through July 1965. The modifications ranged from simple repair to a rather extensive redesign of the CO₂ reduction unit to reduce the leakage of recycle gas in the Bosch mode of operation. The final design descriptions of this section of the report correspond to the modified designs which were delivered to NASA/LRC. Descriptions contained in previous sections of the report may differ from those that appear in Section 6.

6.1 RELIABILITY AND QUALITY ASSURANCE

6.1.1 RELIABILITY AND QUALITY ASSURANCE PROGRAM. The reliability and quality assurance program under which the prototype system was designed, produced, and assembled is summarized by Figures 6.1-1 and 6.1-2. The first diagram, "Reliability and Quality Assurance Program for Development Items", was issued and maintained as a guide to those participating in the program at both the contractor and subcontractor level. The second diagram, "Project Quality Assurance Activities", was issued and maintained as a guide for contractor tasks associated with the assembly of the prototype system. Contractor tasks and responsibilities were documented in detail in the form of program plans. One such plan was the "Life Support System Quality Control Program Plan" issued in conjunction with division reliability and quality control functions; another was a report issued to define the "Cleaning Requirements and Cleanliness Controls" to be employed in contractor manufacturing and assembly. Figure 6.1-3, "Source Acceptance Inspection (SAI) Guide", outlines the execution of reliability and quality assurance tasks during the demonstration tests and inspection conducted at each subcontractor's facility.

6.1.2 QUALITY ASSURANCE PROBLEMS

6.1.2.1 Causative Factors. Equipment reliability and quality deficiencies experienced during the development program were directly related to the following factors in the equipment producer's program.

- a. Understanding of the quality assurance provisions of the specification(s).
- b. Scope and depth of the design analyses.
- c. Communications between analytical, design, and production personnel.

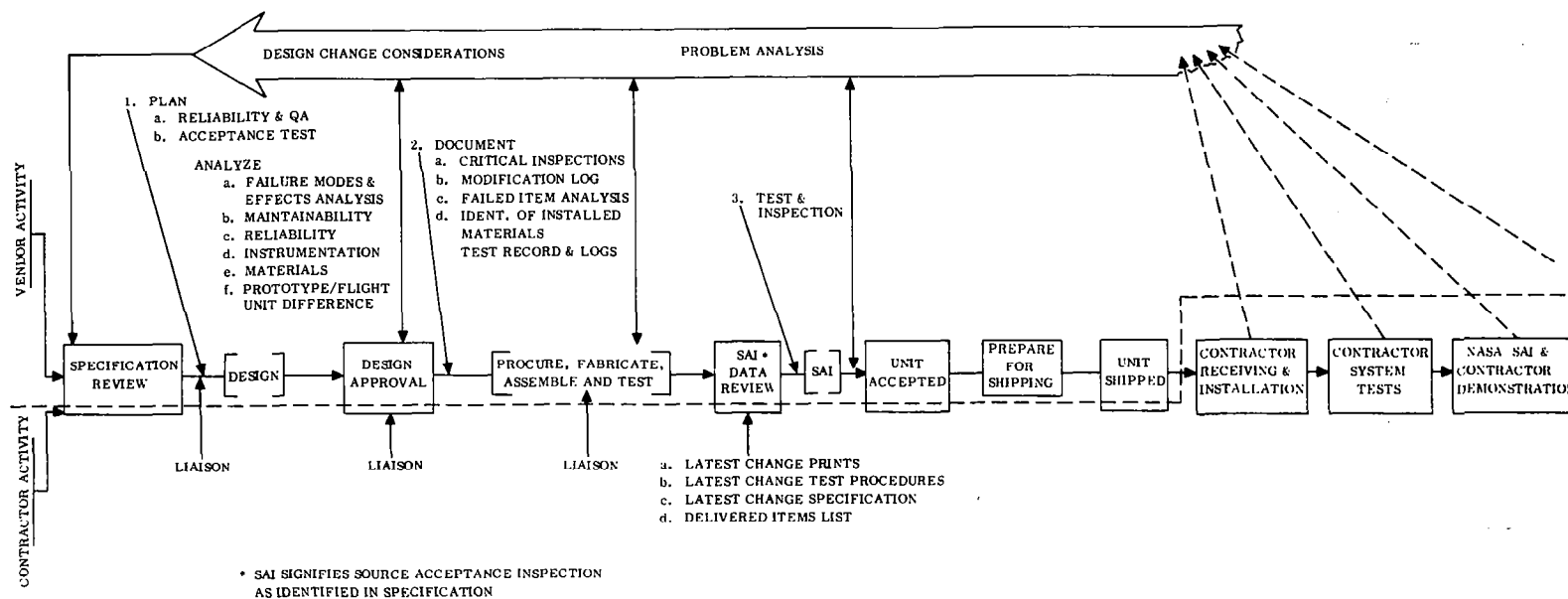


Figure 6.1-1. Reliability and QA Program Development Items

- d. Familiarity and experience with production of development hardware for aerospace flight applications.
- e. Personnel assignments with respect to skills required for the specific tasks.
- f. Selection of available hardware for compatibility with the application.
- g. Selection of materials for compatibility with the application.

When the producer was a subcontractor, product excellence was in direct proportion to the scope and detail of program control exercised by the contractor. Program monitoring and control was effective when there was a mutual detailed understanding of the problems involved, and application of this information to the production of equipment. The seriousness of the problems experienced was not directly associated with the inherent complexity of the development task and only indirectly, if at all, with advancement in the state of the art.

6.1.2.2 Examples of Deficiencies. The significant equipment failures and deficiencies, both functional and quality, have been detailed either in existing reports or in other sections of this report. However, specific examples can be given to illustrate the points covered in the previous paragraph.

- a. CO₂ Reduction Unit. Problems experienced with this unit in its initial configuration involved:
 - 1. Electrical and mechanical failures because the unit was constructed by relatively inexperienced laboratory technicians and engineering personnel and did not reflect the main stream of the producer's capability. Some of the hardware was not compatible with the application.
 - 2. Unnecessary complexity in the basic design led to materials overstress and failure, primarily because engineering analysis and design studies did not effectively continue beyond the formation of a basic functional model. Design of the system was merely the direct mechanization of the elementary functional model.
- b. CO₂ Concentration Unit. Only minor hardware and material compatibility problems were experienced with this unit. Workmanship was excellent because the unit was constructed by the best technicians available to the producer. Program control was excellent.
- c. Catalytic Burners. This unit exhibited essentially trouble-free operation during Convair testing. Where problems existed in the fabrication stage, they appeared to be associated with the fact that the production skills available were geared to construction of experimental models rather than with production of developmental aerospace flight hardware.

- d. Waste Management Unit. . This unit was produced by the same organization as the catalytic burners and, although generally satisfactory, developed motor and bearing failures due to poor selection of available components. Although this unit contained but few major workmanship flaws and design deficiencies, its overall condition reflected the same basic problem as the foregoing and for the same reasons.

The operational difficulties that resulted from these problems ranged from inadequate performance to component failures produced by load and temperature over-stress, corrosion, leakage, and premature wearout.

In summary, it can be stated that equipment problems existed either as functional, strength of materials, or quality problems wherever specifications had not been carefully followed, fabrication skills were inadequate or inappropriate, engineering application experience was low or program controls had been insufficient. Whenever problems were clearly defined and the program controls strengthened, corrections made to the deficient area of the program resulted in significant equipment improvements.

6.1.2.3 Significance of Deficiencies. The primary significance of the equipment deficiencies that appeared at various times within the program can be related to a variety of program considerations such as cost, schedule, or product acceptability in terms of appearance, design performance, and reliability.

The significance of the deficiencies can best be related to two of these considerations: the requirement for additional program activity to correct the deficiencies, and the equipment failures experienced during the system tests.

The nature, extent, and results of the deficiency correction activity have been formally documented with the majority of the information appearing as technical reports listed in the Appendix. A summary of equipment failures, all of which occurred in initial phase testing, is covered in Table 6.1-I. Of the 24 failing components it can be reasonably stated that 15 (13 for subsystems and 2 for support equipment) would have caused a shutdown of a full-scale system test prior to its scheduled termination or have significantly reduced system performance for the duration of the test. During this same initial period, subsystems were accumulating approximately 60 hours each as an average value while test support equipments were accumulating approximately 500 hours each. During the final phases of test approximately 20 hours of additional time was recorded against subsystems and 100 hours against support equipment with no component failures.

By applying total failures experienced to total test time for the initial phase of testing, a gross failure rate (0.22/hr) can be obtained. However, only 4 of the 13 failures appeared in the latter 60 percent of the test period. Thus for the first portion the rate might be said to have been 0.38/hr and for the second portion, 0.11/hr. The rate for the test support equipments was less than 0.003/hr. Even more important

Table 6.1-I. Summary of Equipment Failures During System Test

SUBSYSTEM & TEST TIME	FAILING COMPONENT	TYPE OF FAILURE	CAUSE OF FAILURE	EFFECT ON TEST	POTENTIAL FOR RECURRENCE
CO ₂ Concentrator 140 hours	Actuator, Valve	Leakage (external)	Null adjustment	Proceed on alternate mode	Null adjustments mode but can occur
	Accumulator Bypass Valve	Leakage (internal)	Stroke out of adjustment	Lowers removal effectiveness	Null adjustments mode but can occur
	DC-331 Valve	Leakage (external)	Seal deterioration	Proceed on alternate mode	Problem eliminated
CO ₂ Reduction 50 hours	Pressure Switch	Failure to actuate	Corrosion	Shut down of function	Problem eliminated
	Precooler	Leakage	Strength of materials and workmanship	Shut down of function	Problem eliminated
	DC-331 Valves (4 failures)	Leakage (external)	Materials failure	Limits test time	Problem significantly reduced by improved valves
	Heating Element	Burnout	Design produced overtemperature	Alternate mode required	Redesign reduces heater to secondary function
	Relief Valve (Sabatier)	Leakage (internal)	Contamination	Alternate mode required	Significantly reduced
Air Evaporation 100 hours	Blower (2 failures)	Failure to start	Corrosion locked rotor	Alternate mode required	Reduced but still present
	Temperature Control Valve	Erratic operation	Sticking	Requires manual control and reduces performance	Problem eliminated
	L/G Separator	Stall	Excessive bearing and load drag	Alternate mode required	Reduced but present
	Wick Temp. Thermistor (2 failures)	Failure to operate	Breakage	Alternate mode and/or manual control	Redesign significantly reduces problem
	Thermal Switch	Failure to operate	Breakage during adjustment	Loss of emergency capacity	Procedural changes reduce potential
Electrolysis 20 hours	Pyrometer	Burnout	Shorting during adjustment	Module shut-down	Reduced but not eliminated
Personal Hygiene 10 hours	L/G Separator	Failure to start	Bearing drag caused by corrosion and contamination	Requires alternate mode	Potential reduced but not eliminated
Air Circuit 300 hours	Main Cabin Air Blower	Performance deterioration	Bearing failure	Limit test duration	Bearings improved but problem not eliminated
Heating & Pumping Unit 400 hours	Fluid Heater	External leakage	Weldment porosity	Reduces duration	Eliminated
	Filtration	Flow loss (filter load-up)	Fluid over temperature	Temporary process heat shut-down	Significantly reduced by redesign of heater control and filter circuit
Cooling & Pumping Unit 600 hours	Thermostat Switch	Erratic operation	Contact deterioration due to lack of electrical circuit protection	Reduces performance and requires temporary loss of function	Reduced but present
	Compressor	Loss of function	Compressor lock	Reduces cooling capacity	Somewhat reduced by procedural changes

is that no failures were experienced in the final test and system performance evaluation. Roughly, the present failure rate of the system was greater than zero and less than 0.05/hr. However, far more significance can be attached to the degree of improvement than on the magnitude of the individual rates. Figure 6.1-4 illustrates the rate of improvement during the contractor test program.

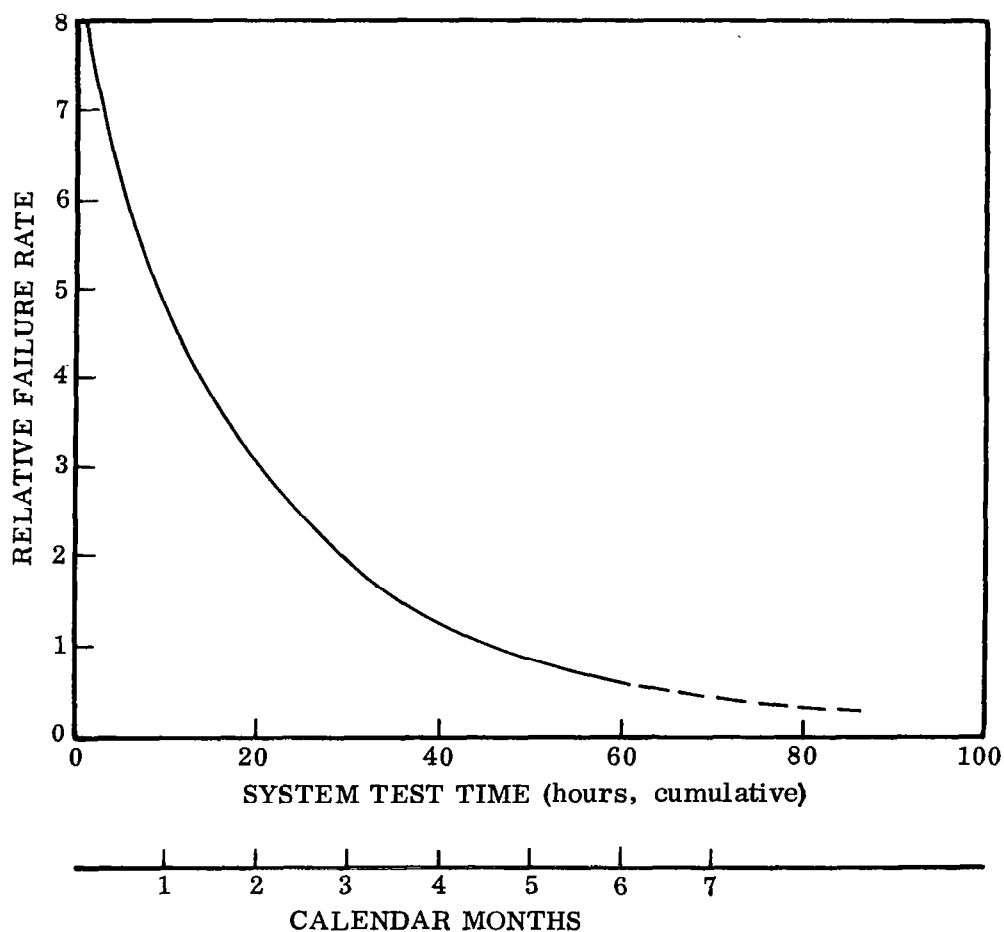


Figure 6.1-4. Failure Rate Improvement During Contractor Tasks

6.2 SUBSYSTEM DESIGNS

6.2.1 THERMAL CONTROL. This section describes the thermal control circuits and components as installed in the LSS test bed. The schematic diagrams of the thermal control circuits reflect numerous changes made to the originally designed circuits to accommodate the continuously updated component thermal requirements.

6.2.1.1 Air Circuit. The installed thermal control air circuit consists of Systems A and B, described in the simplified schematic, Figure 6.2-1. A complete schematic of the circuit is shown in Convair Drawing 64-26182. For additional detailed information including hardware dimensions, refer to Convair Drawing 64-26115.

System A. System A of the thermal control air circuit provides conditioned air to the laboratory and living modules as well as to the catalytic burner and CO₂ concentration unit. This system consists of the following major thermal control components.

- a. Heat exchanger.
- b. Blower.
- c. Air (duct) heater (electronic equipment simulator).
- d. Cabin air temperature control system.
- e. Water separator.

The cabin air heat exchanger is an all-aluminum, cross-counter-flow, fin-tube unit in which the air makes a single pass. The circular liquid tubes have an outside diameter of 0.50 inch with a wall thickness of 0.049 inch and are located on a equilateral (1.25-inch) triangular matrix. Coolant flow to the header is divided between 2 tubes, each of which make 5 passes per traverse row (normal to the direction of air flow) for the 46 traverse rows down the length of the core. The heat exchanger has straight continuous fins with a pitch of 10 per inch. The overall dimensions and general configuration are shown in Figure 6.2-2. Refer to Convair Drawing 64-02020 for additional detailed information.

The heat exchanger has a design cooling capacity of 13,230 Btu/hr with 900 lb/hr ($\rho = 0.050 \text{ lb/ft}^3$) of air entering the unit at 90°F with a specific humidity of 0.01 lb/lb of dry air and leaving at 40°F. This performance corresponds to a coolant (FC-75) flow rate of 1600 lb/hr at an inlet temperature of 36°F.

The main cabin air blower (Remselair Blower, Model AV5500-300, Remsel Industries, Chicago) is a vane axial unit powered by a 3-phase, 200-vac, 400-cps, 0.7-hp motor. The unit has a design capacity of 300 scfm against a static pressure of 8.1 inches of water at a corresponding speed of 11,275 rpm. The blower housing has an outside overall diameter of 6-59/64 inches and a length of 7-35/64 inches.

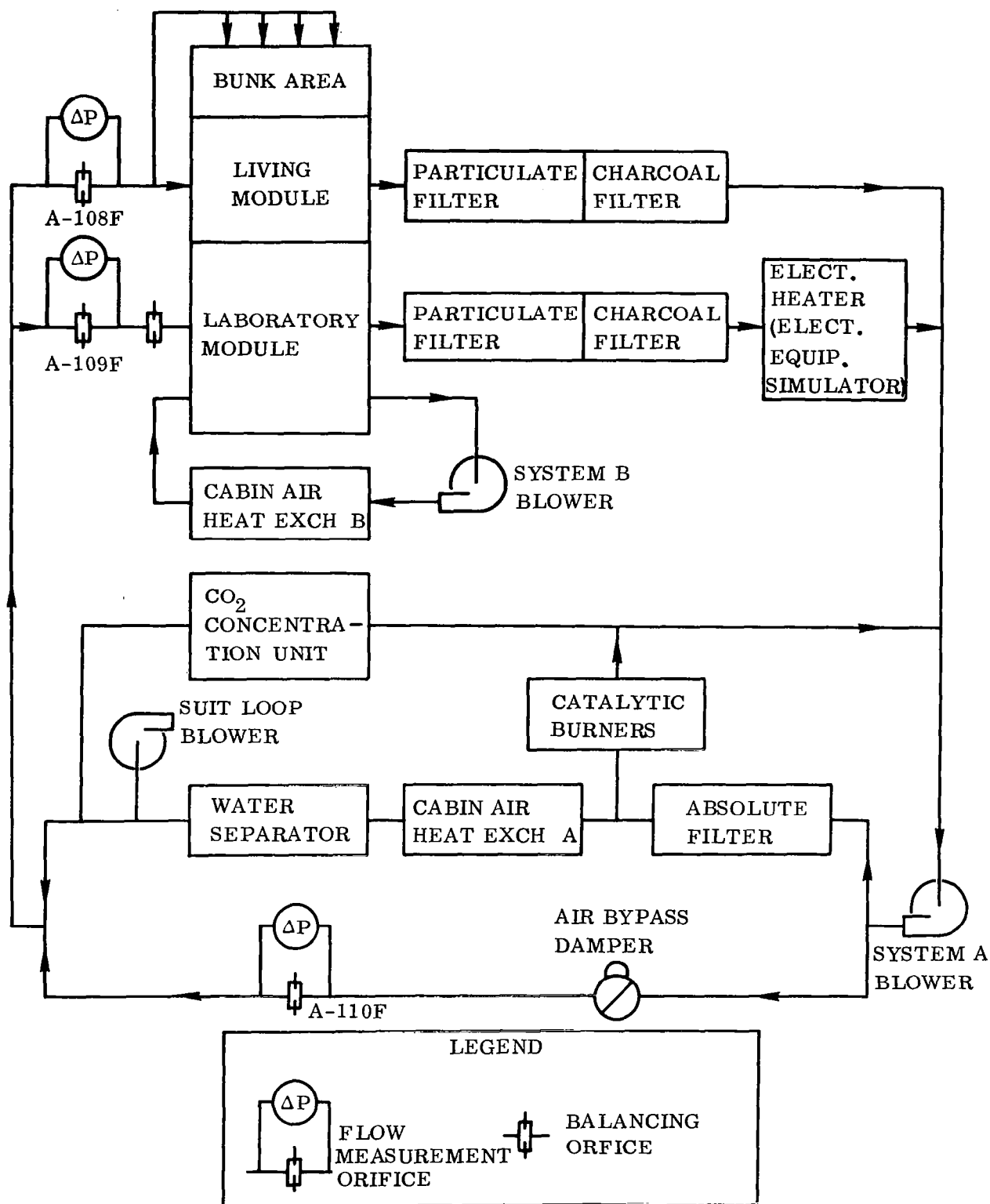


Figure 6.2-1. Installed Thermal Control Air Circuit Flow Schematic

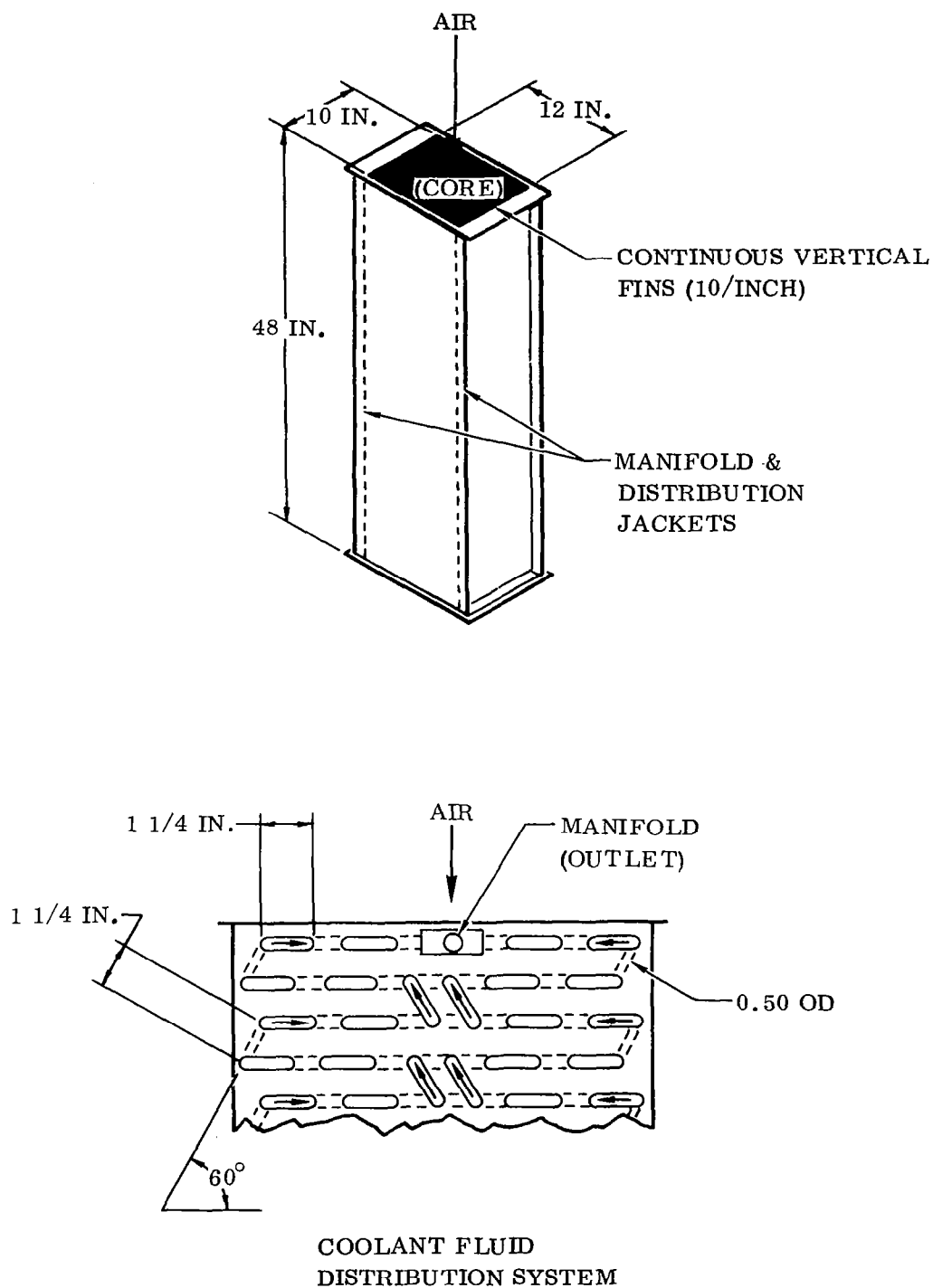


Figure 6.2-2. Cabin Air Heat Exchanger (System A)

The air (duct) heater (Chromalox Part No. PT-2407, Edwin L. Weigand Co., Pittsburgh) is a strip heater with a chrome-steel sheath and has a rated capacity of 750 watts at 120 vac. The unit is 1-1/2 inches wide, 23-3/4 inches long, and has a watt density of 10 watts/in.². The electrical input to the heater is controlled by a variable transformer (Model 3TF117, Superior Electric Co., Bristol, Connecticut) located in the ground control console.

The cabin air temperature control system consists of (1) an integrated electronic relay and modulating motor unit, and (2) a remote temperature sensor and selector. The relay-motor unit (Model M7023A, Minneapolis-Honeywell Regulator Co., Minneapolis) consists of an amplifier, a bridge circuit, and motor all mounted in a common housing. The control has an angular stroke of 160 degrees and a variable throttling range from 1 to 10 degrees. The motor develops a maximum torque of 108 in.-lb.

The remote temperature sensor and selector (Model T7018F, Minneapolis-Honeywell Regulator Co., Minneapolis) is a space thermostat with an adjustable scale range of 55 to 85°F and a nominal control element resistance of 1000 ohms.

The water separator, although performing a thermal control function, is described independently in Convair Report 64-26231, "Liquid/Gas Separation Mechanisms".

System B. System B was installed to provide additional sensible cooling to the laboratory module. This additional cooling capacity was required to offset the increased heat load introduced by the various LSS components. This system consists of the following thermal control components.

- a. Heat exchanger.
- b. Blower.

The cabin air heat exchanger is identical to that installed in System A except that this unit is 34 rows long and has an overall length of 36 inches. The heat exchanger has a design (sensible) cooling capacity of 12,950 Btu/hr with 2325 lb/hr ($\rho = 0.050$ lb/ft³) of air entering the unit at 71°F with a specific humidity of 0.008 lb/lb of dry air and leaving at 48°F. This performance corresponds to a coolant (aqueous propylene glycol, 40 percent by volume) flow rate of 1190 lb/hr at an inlet temperature of 46°F.

The air blower (Remselair Blower, Model No. AV-0104-3450, Remsel Industries, Chicago) is a 2-stage vane axial unit powered by a 115/208 vac, 3-phase, 60-cps, 1-hp motor. (A 400-cps motor is being procured for this unit.)

6.2.1.2 Liquid Coolant Circuit. The heat-transport fluid originally used in the coolant circuit was FC-75. However, during the system tests subsequently conducted, this clear fluid leaked easily and evaporated rapidly when exposed to the atmosphere.

Hence, small leaks could not be visually located. No other acceptable method of leak detection could be developed. Because of these characteristics, and the high cost of replacement fluid, it was decided to discard the FC-75 and use aqueous propylene glycol (40 percent propylene glycol by volume). This composition was subsequently changed to 27 percent propylene glycol (by volume) to reduce the pumping power requirements.

Distribution Circuit. Figure 6.2-3 is a simplified schematic of the installed thermal control liquid coolant circuit. A complete schematic of the circuit, including hardware identification and dimensions, is shown in Convair Drawing 64-26181.

The water chiller, cabin air heat exchanger A, and CO₂ reduction unit all require low-temperature coolant for condensing or chilling operations and were located in parallel circuits immediately downstream of the fluid cooling and pumping unit. Heat exchanger B was installed in the fluid circuit immediately downstream of heat exchanger A so that heat exchanger B receives full coolant flow at a maximum temperature of 46°F.

The electrolysis unit was located in a bypass circuit downstream of heat exchanger B. This location permits the unit to receive a constant coolant flow at a temperature of approximately 65°F. A fixed orifice was installed in the main circuit parallel to the electrolysis unit to divert the required coolant flow to the unit.

The water recovery units and the coolant-fluid heater (electronic equipment simulator) were installed in series downstream of the water chiller to take advantage of the low-temperature coolant leaving the chiller.

The CO₂ concentration unit, which has large cyclic cooling requirements, was located downstream of the CO₂ reduction unit to minimize its effect upon the remainder of the circuit.

This distribution circuit permits each component to receive coolant at the lowest available temperature without producing excessively high circuit-pressure drop or increasing the total fluid-flow rate above that required to satisfy the cooling requirements of the low-temperature units.

Balancing valves are installed in all parallel branch circuits to allow flow rate adjustment. Enough calibrated flow-measurement orifices have been installed to permit direct or indirect (sum-and-difference) determination of the coolant flow rate to each key component in the circuit.

Fluid Cooling and Pumping Unit. The fluid cooling and pumping unit (radiator simulator) is a mechanical refrigerant device that uses two identical refrigerant circuits to provide cooling. Each refrigerant circuit consists of a hermetically sealed compressor, a water-cooled condenser, a shell-and-tube chiller, a receiver, a heat interchanger, and associated valves and controls.

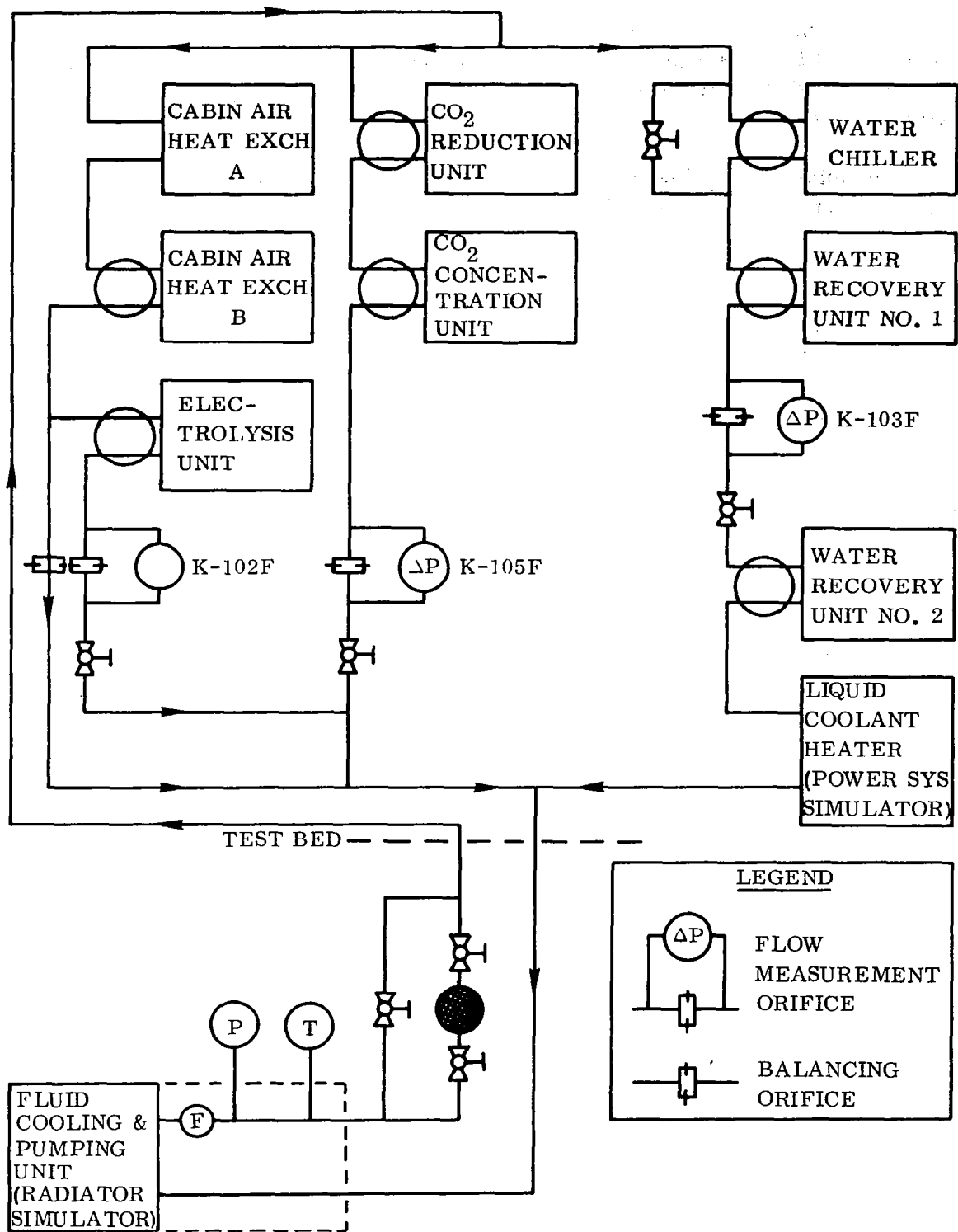


Figure 6.2-3. Liquid Coolant (Propylene Glycol) Circuit Flow Schematic

High- and low-pressure cutoff switches were installed on each compressor to protect the unit from damage in the event of system malfunction. A pressure-relief valve (set at 350 psi) was also provided on each refrigerant receiver to protect the circuit from overpressure.

The total coolant flow is circulated through the chiller by a belt-driven positive-displacement pump. Excess flow not required for the external (test bed) circuit is short circuited, through a pressure-relief valve and heat interchanger, to the inlet side of the pump.

A 5-gallon reservoir was installed in the coolant circuit to compensate for fluid thermal expansion and contraction.

A thermostatically actuated hot-gas bypass control scheme is employed to control the unit cooling capacity to maintain a coolant-fluid discharge temperature of $32 \pm 2^\circ\text{F}$.

Figure 6.2-4 is a simplified flow schematic of the unit refrigerant and coolant circuits. Refer to Convair Drawings 64-26188 and 64-26189 for detailed schematics of the unit fluid and electrical circuits respectively. C. G. Hokanson Co., Inc., Drawing 6403000 is an assembly drawing of the unit.

Coolant Fluid Heater. The coolant-fluid heater (electronic equipment simulator) is a commercial, insulated, oil-circulation heater with a rated capacity of 2500 watts at 120 vac. The steel-sheath heating elements have a watt density of 22 watts/in.².

The unit is equipped with a high-temperature thermostat that activates a remote warning light when the coolant exit temperature from the heater reaches $150 \pm 5^\circ\text{F}$. An adjustable high-temperature thermal-cutout switch (with manual reset) is an integral part of the heater. This cutout opens the heater electrical circuit if the coolant temperature in the heater exceeds the preselected value ($175 \pm 1^\circ\text{F}$).

The electrical input to the heater is controlled by a variable transformer with a capacity of 2700 watts. The transformer is located in the ground control console.

Figure 6.2-5 is a simplified schematic of the unit. Refer to Convair Drawing 64-26105 for additional detailed information.

6.2.1.3 Process Heat Circuit. The process-heat circuit utilizes DC 331 as the heat-transport fluid. Figure 6.2-6 is a simplified schematic of the installed thermal control process-heat circuit. A complete schematic of the circuit, including hardware identification and dimensions, is shown in Convair Drawing 64-26181.

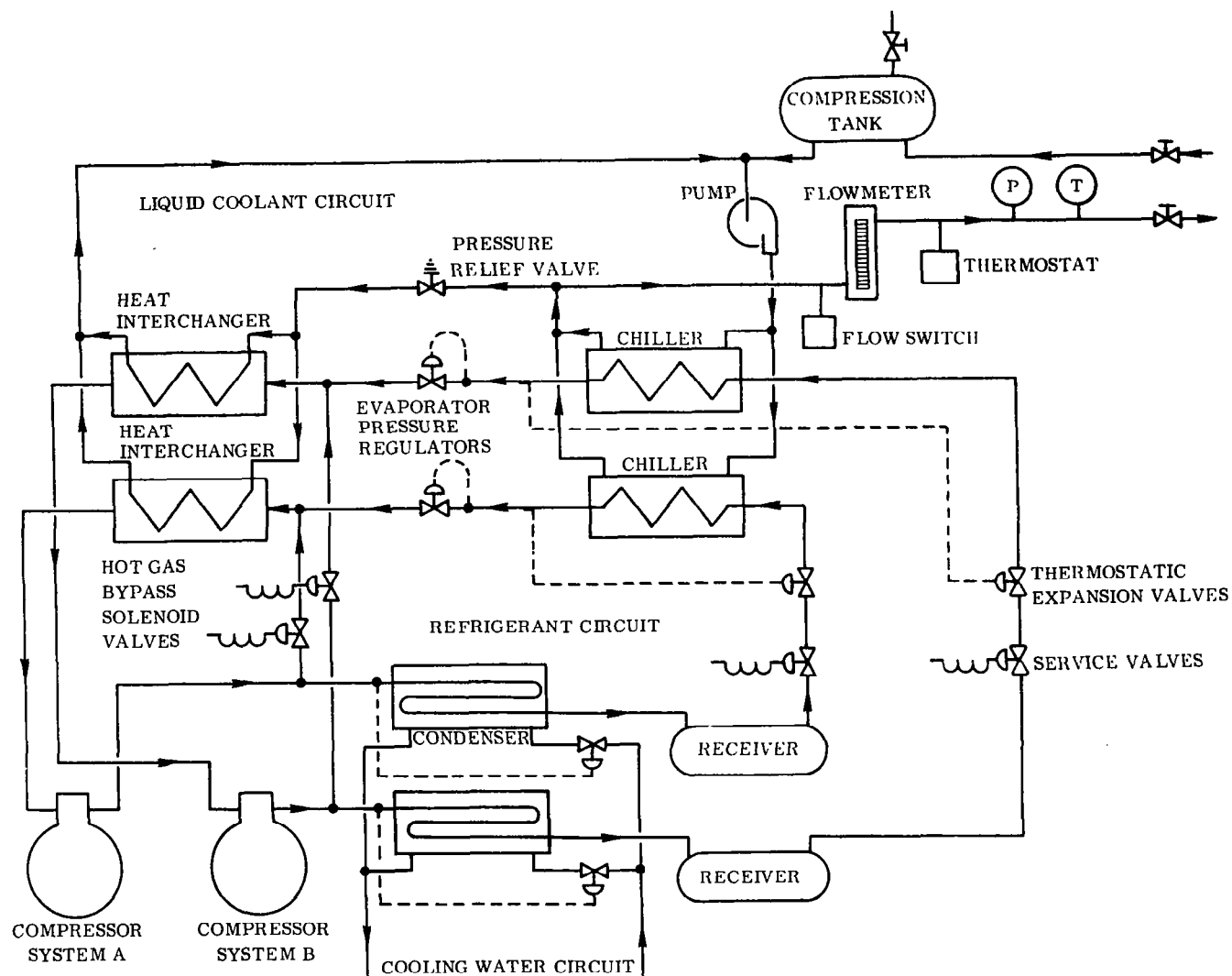


Figure 6.2-4. Fluid Cooling and Pumping Unit Flow Schematic

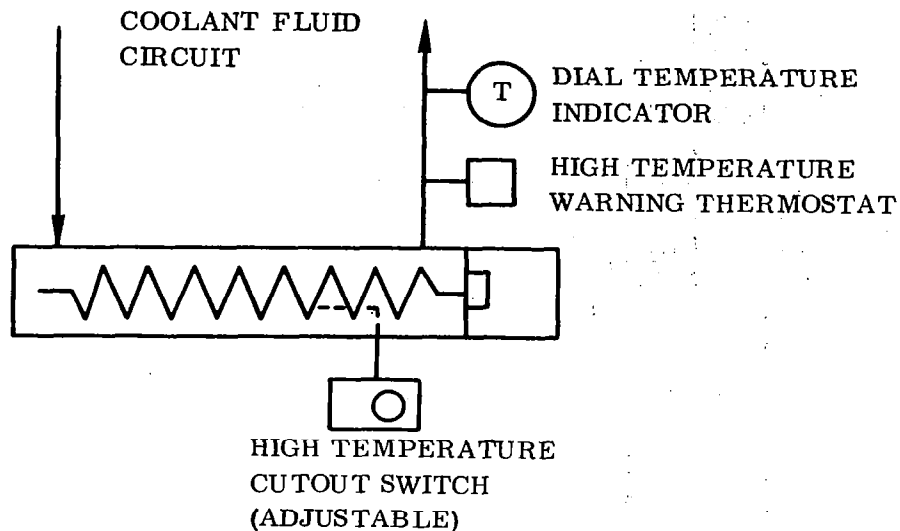


Figure 6.2-5. Coolant Fluid Heater

The CO₂ concentration unit and CO₂ reduction unit (Sabatier reactor) require high-temperature fluid for desorption and preheat operations respectively. Therefore, these components were located in parallel circuits immediately downstream of the fluid heating and pumping unit.

The heat-transport fluid flow from the CO₂ concentration unit is subject to large cyclic temperature variations due to the cyclic operation of the unit. Hence, the fluid from this unit is returned directly to the fluid heating and pumping unit to minimize its effect upon the remainder of the circuit.

The water recovery units were located in a parallel arrangement downstream of the reduction unit to take advantage of the relatively constant high-temperature fluid leaving this unit.

The food water heater was located in series to the water recovery units in the CO₂ reduction unit branch circuit. The feces dryer and wash water heater (connected in series) were originally connected in parallel to the food water heater. However, heat losses associated with the long lengths of interconnecting lines from the water recovery units to these units, coupled with the low fluid-flow rate, resulted in excessive fluid-temperature drop. The resulting fluid inlet temperature to the feces dryer and food water heater was inadequate to produce the desired operating characteristics. There-

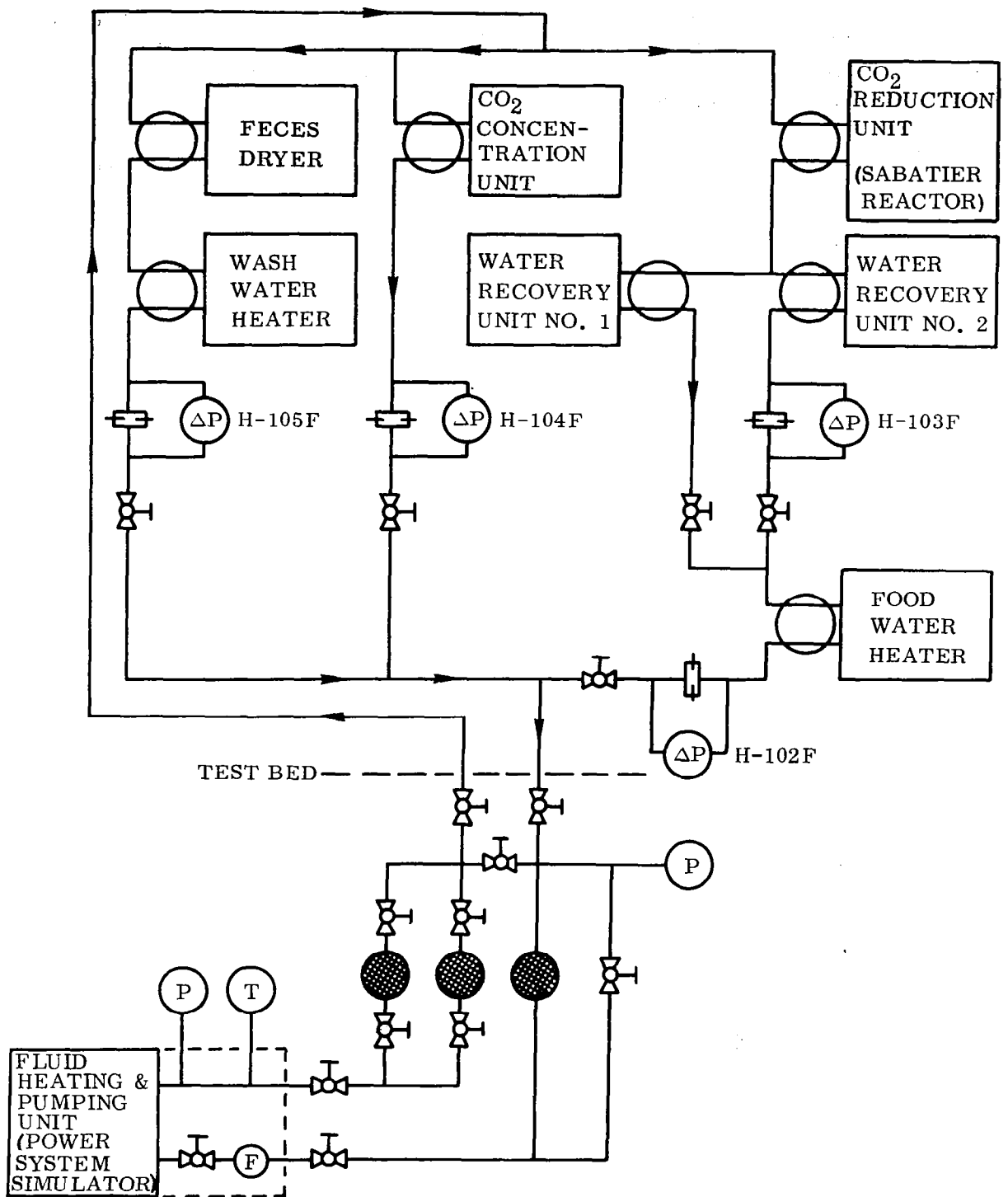


Figure 6.2-6. Process Heat (DC-331) Circuit Flow Schematic

fore, the feces dryer and wash water heater (connected in series) were installed in another parallel fluid circuit immediately downstream of the fluid heating and pumping unit. This change permitted the food water heater to receive the total fluid flow from the water recovery units and resulted in a substantially higher fluid inlet temperature while simultaneously eliminating a substantial length of fluid lines.

This distribution circuit permits each component to receive fluid at the highest available temperature without producing excessively high pressure drop. It also permits the use of a minimum fluid-flow rate compatible with the heating requirements of the high-temperature units and physical location of components.

Balancing valves were installed in all of the parallel branch circuits to allow flow-rate adjustment. Fixed orifices were installed in these circuits as indicated in Convair Drawing 64-26181 to minimize the effect of component pressure-drop variations (caused by component fluid controls) upon the circuit fluid-distribution balance.

Enough calibrated flow-measurement orifices have been installed to permit direct or indirect (sum-and-difference) determination of heat-transport fluid-flow rate to each component in the circuit.

6.2.1.4 Fluid Heating and Pumping Unit. The fluid heating and pumping unit (power system simulator) basically consists of an electric heater, a positive-displacement pump, and a 5-gallon reservoir to compensate for fluid thermal expansion and contraction.

The total fluid-flow rate is initially circulated through the electric heater. The fluid-flow rate to the external (test bed) circuit is controlled by an adjustable throttling valve on the inlet side of the unit. Fluid flow produced by the pump in excess of that required for the external circuit is short circuited, through a manually controlled bypass valve, to the inlet side of the pump.

The fluid discharge temperature from the unit is maintained at an adjustable preselected value ($400 \pm 10^{\circ}\text{F}$) by means of a bridge-amplifier circuit that continuously modulates the heater input voltage in response to the measured difference between the actual fluid discharge temperature and the desired value.

An adjustable high-temperature cutout switch (with automatic reset) is an integral part of the electric heater. This switch opens the heater electrical circuit if the fluid temperature in the heater exceeds the preselected value (425°F).

A no-flow switch was also provided. This switch, which senses the fluid-pressure drop across the heater, de-energizes the complete unit if this pressure differential falls below a preselected value corresponding to a minimum fluid-flow rate.

Figure 6.2-7 is a simplified flow schematic of the unit. Refer to Convair Drawings 64-26186 and 64-26187 for detailed schematics of the unit fluid and electrical circuits respectively. C. G. Hokanson Co., Inc., Drawing 6404000 is an assembly drawing of the unit.

6.2.1.5 Cabin Air-Water Separator. The cabin air-water separator controls cabin humidity by removing water droplets from the air stream in the cabin air duct after they have been condensed and agglomerated by the System A cabin air heat exchanger. Condensate is continuously transferred to the CT-2 collection tank of the water management system by an electrically driven pump that matches the catch rate of the separator. The basic separation function is performed with no moving parts (static), by directing entrained-water droplets to porous-metal plates that provide a liquid/gas interface through capillary action permitting water to flow through the plate to the separator pump. If air pressure forces are less than capillary forces, water flows through the plates to the separator-pump inlet. The air is excluded.

Efficiency is measured by the percentage of condensed water removed by the separator, and is directly related to the separator configuration for a given water-droplet size, distribution, and air velocity. The basic configuration used in the life support system was developed by the Electromechanical Division of TRW but was modified by Convair to improve performance and reduce air leakage. Although the anticipated moisture output of a four-man crew is 19.6 lb/day, the separator specification required a peak water-removal capacity of 3.7 lb/hr from a 900 lb/hr air stream in a 10 psia cabin. The allowable entrained moisture in the discharge air was 0.15 lb/hr, corresponding to an efficiency of 96 percent.

Current Configuration. The water-separator and header assembly is a modification of the original TRW configuration, consisting of a flanged housing installed in the vertical section of the cabin air duct downstream of heat exchanger A, and an array of porous-plate assemblies. The porous-plate assemblies are aligned with the duct, but baffles are employed to deflect the air and direct entrained-water droplets to the plates where they are "swallowed" by capillary action (Figures 6.2-8 through 6.2-10). Each double-plate assembly is made of two porous sheets of sintered nickel attached to a supporting frame to form a water cavity. End-plate assemblies have only one porous sheet; the side facing the separator housing is solid metal. The water cavities are connected at the top and bottom to common tygon manifolds that lead to the pump. The number of double plates has been reduced from nine to four to accommodate the baffles. Net flow area was reduced from 95 in.² to 38 in.² and the air makes a 180-degree turn at each of the eight baffles.

The TRW pump failed to deliver water at the required discharge pressure, was not self-priming, and was found to lose prime at a suction head of 0.3 psig. The pump was removed from the instrument and control panel and replaced with a modified Gorman Rupp oscillating pump (Figure 6.2-11). An additional pump of this type was installed to remove liquid carryover from the sump downstream of the separator and return it to the duct upstream of the heat exchanger.

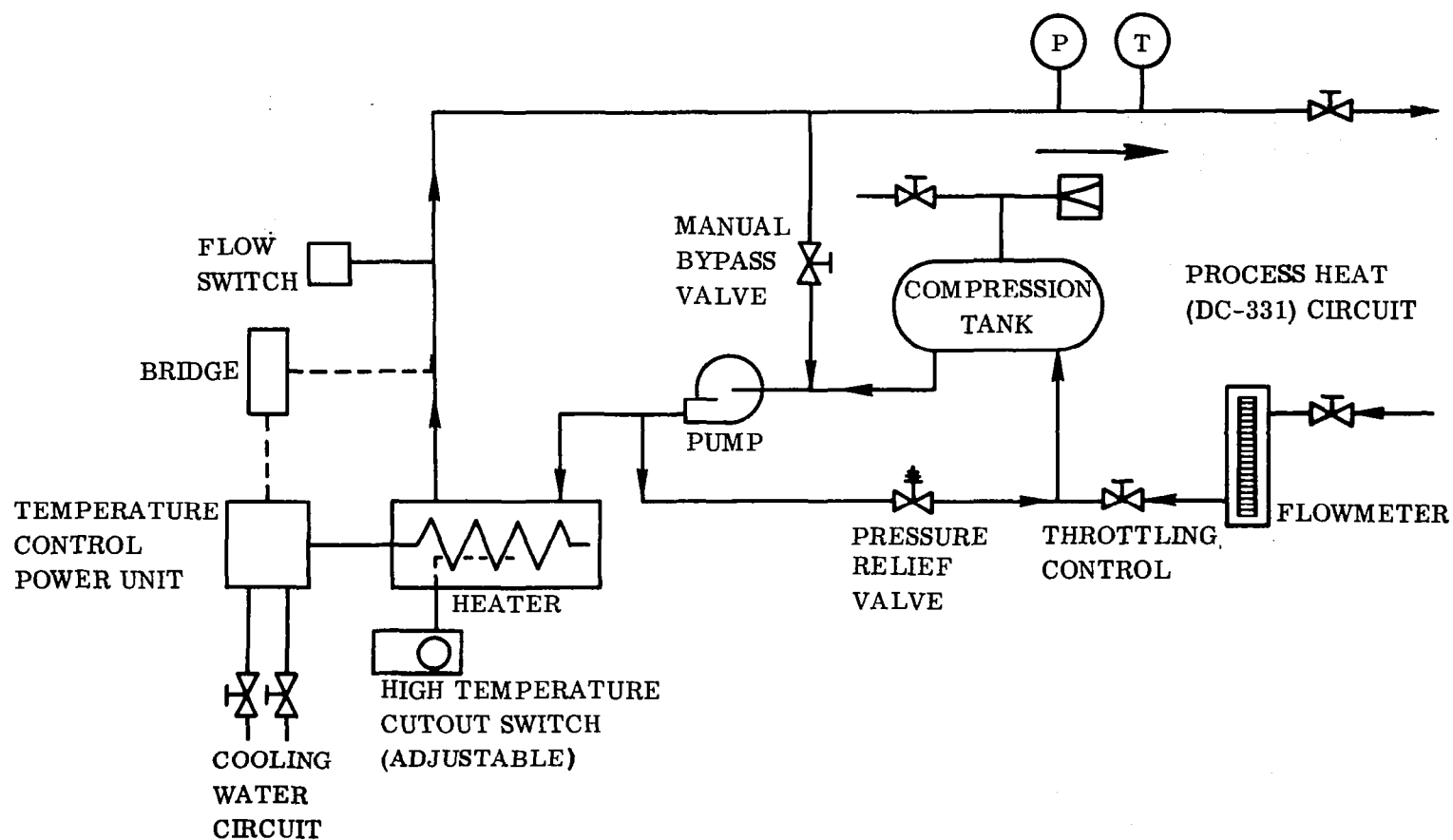


Figure 6.2-7. Fluid Heating and Pumping Unit Flow Schematic

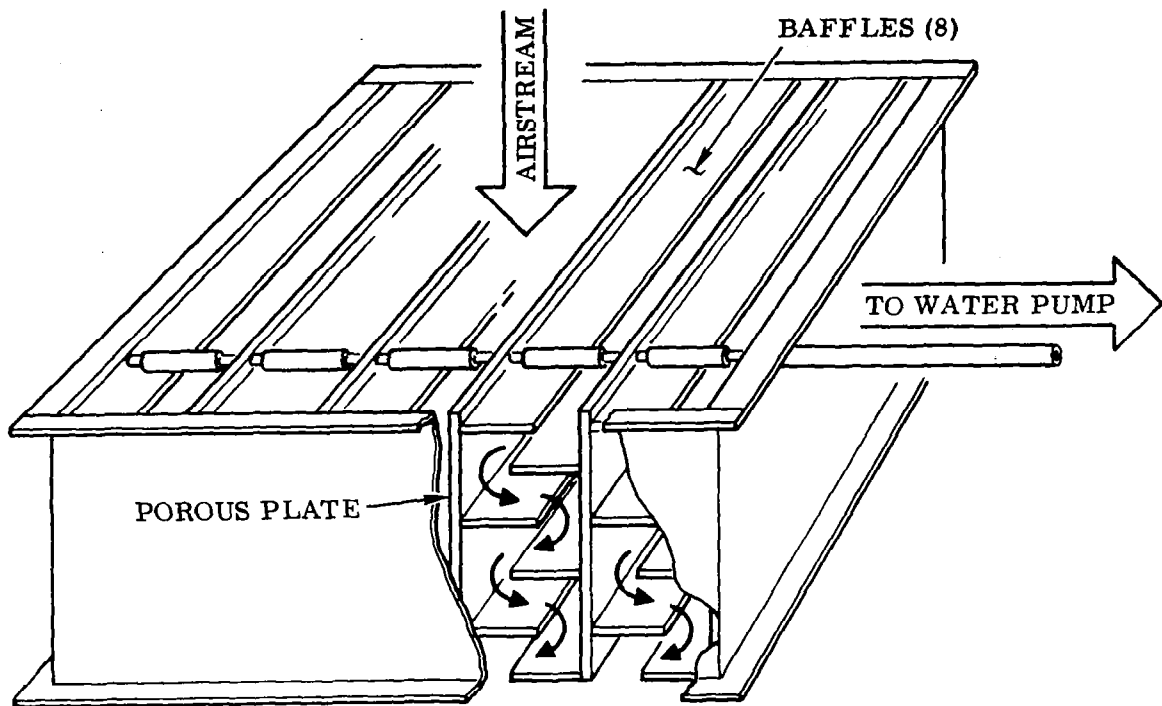


Figure 6.2-8. Air Current Configuration

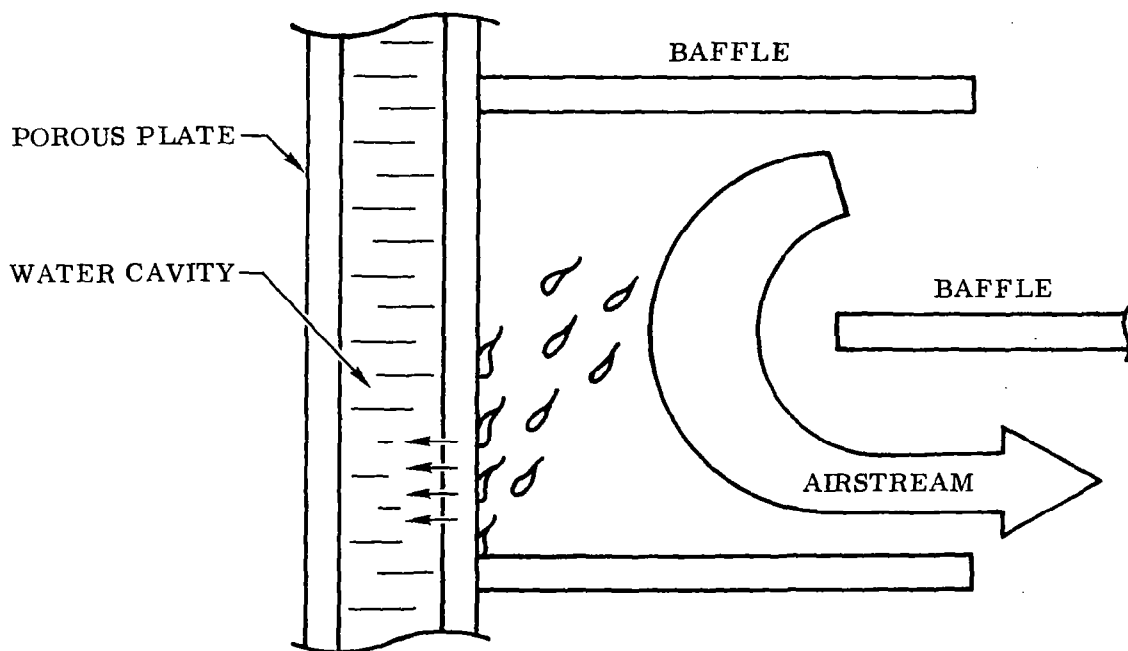


Figure 6.2-9. Air Deflection

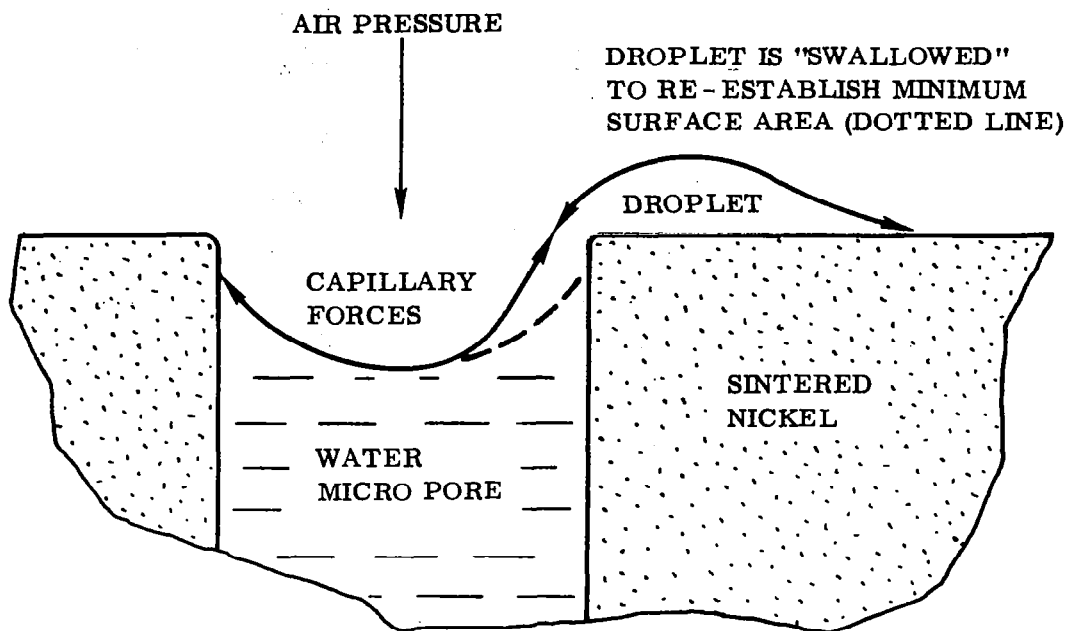


Figure 6.2-10. Capillary Forces

Developmental History. The TRW configuration employed stainless-steel-wool packing between the porous-plate assemblies contained in wire mesh. Chevron-shaped grooves in the end plates were intended to impart a V form to the packing so that water droplets might migrate toward the porous plates under the influence of the dynamic pressure of the air stream (Figure 6.2-12).

When tested at Convair, most of the plate assemblies showed severe air leakage at 1-psi differential pressure due to ineffective or damaged solder between plate and frame. Small specimens were fabricated from the TRW plates to evaluate both an adhesive bonding and attachment by welding. A satisfactory bond was obtained with FM 1000 adhesive on a 0.187-inch frame for the sealing surface in lieu of the 0.09-inch of the TRW design. Porous-plate material and the remaining parts were shipped from TRW on 3 December, and new plate assemblies were fabricated by Convair using adhesive bonded chem-milled plates.

The bonding technique has proven to be workable but plate construction is such that cracking and puncture occur rather frequently during the bonding process and in subsequent handling operations. Further complicating the problem of plate integrity is the difficulty in obtaining satisfactory control and test of plate quality. These factors coupled with the inherent difficulties in maintaining uniform and continuous plate wetting during operation have resulted in a continuing plate-leakage problem throughout the test program.

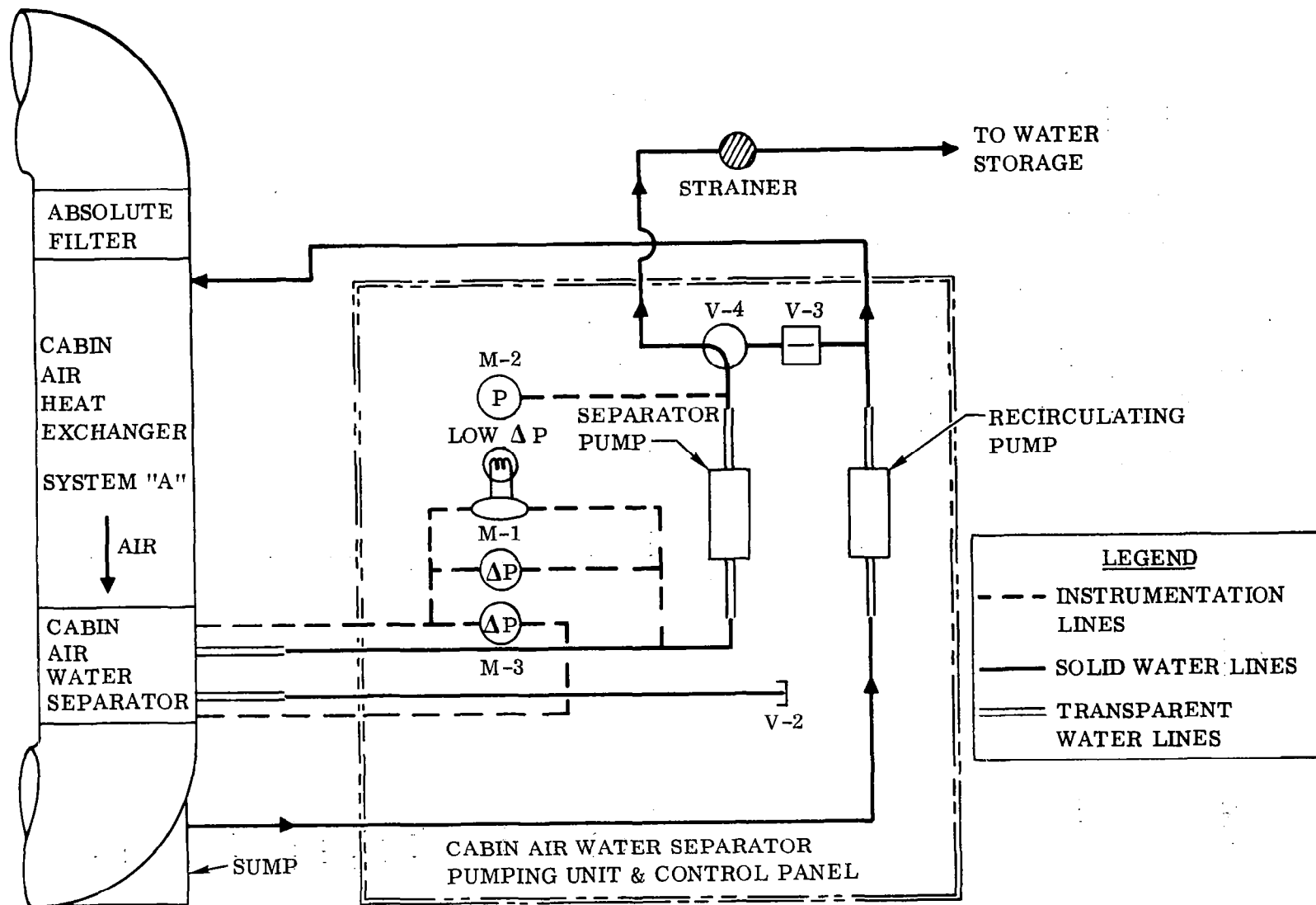


Figure 6.2-11. Cabin Air/Water Separator Schematic

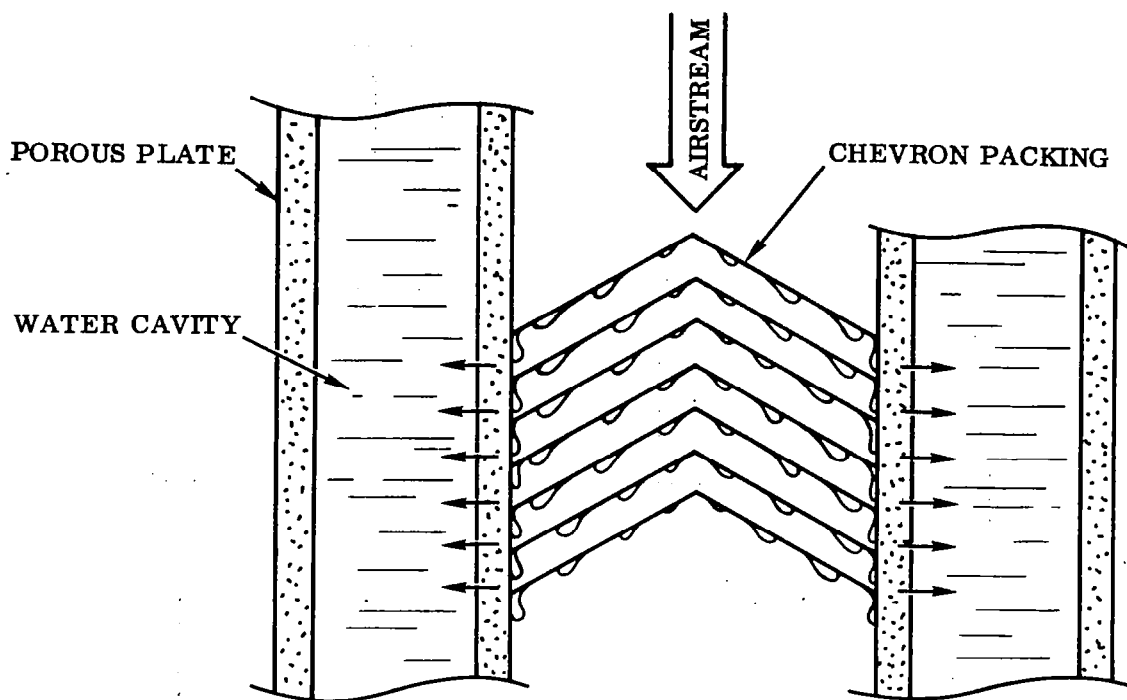


Figure 6.2-12. Chevron Packing

Two new configurations that produced a more positive flow direction were fabricated and tested for comparison with the original separator assembly that employed open-matrix, metallic-mesh chevrons to direct the entrained water onto the plates. The first essentially added a series of solid-plate V baffles to the original metal-mesh chevrons. The second discarded the metal-mesh agglomerator and substituted a series of offset, straight (flat-plate) baffles to produce an air-flow labyrinth across the separator.

Due to the lack of definitive information concerning the original pump, tests were conducted to determine its pumping characteristics (Figure 6.2-13). These tests showed that the original pump could not meet the desired capacity of 3.7 lb/hr with a suction pressure of 3 psig and discharge pressure of 5 psig. The pump was not self-priming and would lose prime when air bubbles were introduced to the inlet. These deficiencies are directly related to the very low catch rate of the separator and were inherent to the pump design, which attempts to accommodate this catch rate.

Explanation of the observed characteristics is as follows.

- a. Failure to pump to design pressure: Deformation of the diaphragms at 5 psig reduced the volume per stroke below the 0.9 cc required to deliver 3.7 lb/hr. Deformation at 5.7 psig completely canceled pumping action and the effective stroke was zero.

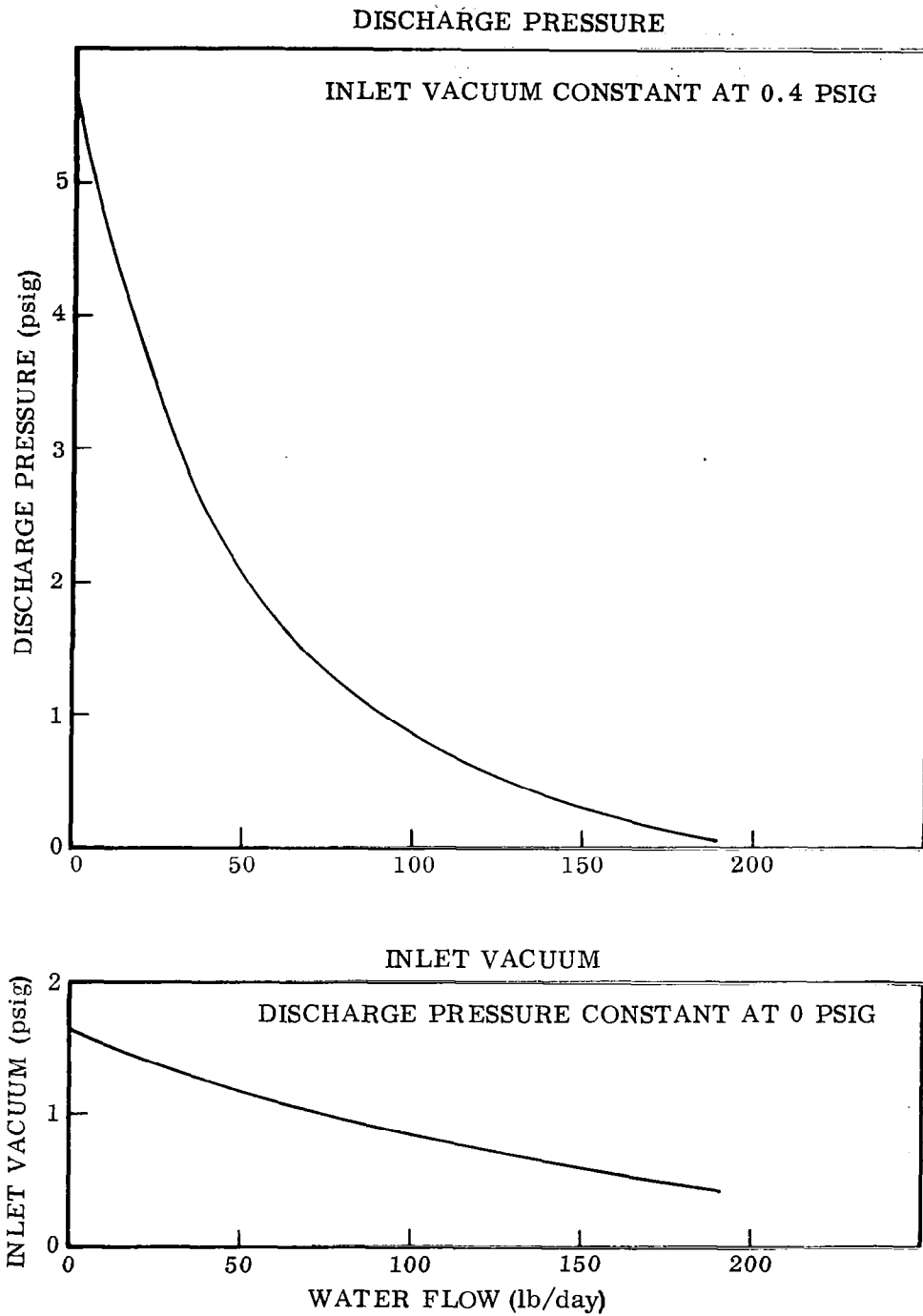


Figure 6.2-13. TRW Pump Capacity

- b. Failure to pump against 3.0 psig vacuum: The effective stroke was reduced to zero by the inlet pressure bias. There is evidence that the bias worked as intended, but with excessive sensitivity.
- c. Failure to self-prime: The volume per stroke was extremely small compared with the total volume of the pump chambers, check-valve cavities, and empty inlet lines - a ratio of about 100:1. The pressure change per stroke was proportional to the volume ratio, or about 4 inches of water for full pump stroke. This was the cracking pressure of the check valves, so that the pump would not self-prime.
- d. Loss of prime due to air bubbles: Prime is lost if the total volume of air bubbles in the inlet line and pump reduces the pressure change per stroke to cracking pressure of the check valves. The tendency is aggravated by the reduction in effective stroke when the pump is working against a vacuum.

As a result of this investigation the original pump was replaced by a Gorman Rupp solenoid-driven, oscillating, two-stage, bellows pump. As shown on Convair Drawing 64-26177, an adjustable controller was installed in the separator-pump electrical circuit to permit manual adjustment of pump displacement and thus adjustment of separator plate ΔP . An additional pump of the same type was added to the circuit to recycle the water carryover, collected in the sump downstream of the separator, to the inlet side of the condensing heat exchanger.

6.2.2 ATMOSPHERIC CONTROL

6.2.2.1 CO₂ Concentration Unit

Operational Description. The function of the CO₂ concentration unit is to maintain CO₂ concentration in the test-bed atmosphere within tolerable limits for crew occupancy. The specific requirement for this unit, as previously described, is to remove a total of 9.28 pounds of CO₂/day from the atmosphere when the test-bed pressure is 10.0 psia and the CO₂ partial pressure is 3.8 mm Hg. Figure 6.2-14 is a flow schematic of the unit. Process air is obtained from the main air conditioning system just downstream of the water separator. The maximum design condition of this air is 55°F saturated, but the concentration unit has compensating controls to provide for an inlet air-temperature range from 34°F saturated to 55°F saturated without adversely affecting unit operation.

The relatively cool, saturated air is drawn into the unit by the system blower (Item 9) and passes first through a silica gel bed (Item 2 or 3) where the air is dried to a low ($\sim -70^\circ\text{F}$) dew point. The air then passes to an air-to-liquid heat exchanger (Item 5) where most of the heat of water adsorption that was absorbed by the air stream is rejected to the coolant fluid (propylene glycol) in the heat exchanger. This is done to obtain relatively cool air at the inlet to the zeolite bed (Item 11 or 12) so that a high

Figure 6.2-14. CO₂ Concentration Unit

CO₂ adsorption capacity may be maintained. As a further aid in maintaining high adsorption capacity in the zeolite bed, an intermediate coolant loop of DC-331 fluid is circulated through the bed. The heat of CO₂ adsorption is rejected to this fluid. The DC-331 fluid then flows through a fluid-to-fluid heat exchanger (Item 24) where this heat of adsorption is rejected from the DC-331 fluid to the propylene glycol coolant fluid and transferred out of the system.

Also included in the intermediate fluid loop is a thermal surge chamber (Item 26). This chamber was included because at the end of any given cycle, the desorbing zeolite bed has hot fluid (~350°F) flowing through the bed. When the beds are switched from the desorb to adsorb mode, the hot fluid within the bed is transferred to the intermediate fluid loop. This transfer would cause a temperature surge in both the process-air loop at the air-to-coolant heat exchanger and also in the coolant-fluid loop at the fluid-to-fluid heat exchanger. The incorporation of the surge tank reduces the influence of this fluid interchange.

Approximately 40-60 percent of the CO₂ is removed from the airstream by adsorption in the zeolite bed. This process air then passes to a fluid-to-air heat exchanger (Item 8) and is heated to over 250°F. From the heat exchanger, the hot air then passes through the desorbing silica gel bed. The bed is heated by the hot process air and the water vapor adsorbed on the previous cycle is desorbed from the bed. This water vapor and the process air pass out of the system and back into the cabin air conditioning system upstream of the main blower. The net exchange of water vapor between the unit and the test-bed atmosphere is zero.

During the period when one zeolite bed is adsorbing CO₂, the other zeolite bed is being desorbed of the CO₂ that had been adsorbed during the previous half-cycle. Hot fluid is admitted to the system through the valve (Item 21). This valve is a three-way valve used to pass the hot fluid either to the zeolite bed or to bypass the zeolite bed and provide fluid directly to the heat exchanger. Valve Items 22 and 23, 28 and 29 act in pairs to direct the hot fluid to the desorbing bed and the coolant fluid to the adsorbing bed. The desorbing bed is initially purged of air by pumping the desorbing system to a pressure of about 2 psia through use of the CO₂ transfer pump (Item 16). The air pumped out of the system is returned to the unit inlet through the CO₂ diverter valve (Item 17). Shortly before the end of purge, hot fluid is diverted to the bed to start heating of the bed to desorb the CO₂. In the thermal-desorption mode, the pump continues to operate, Item 17 acts to divert the gases from the bed to the accumulator (Item 18), and operation continues until the adsorbed CO₂ has been desorbed and transferred to the accumulator. A heat exchanger at the inlet to the CO₂ pump reduces the temperature of the evolved CO₂ to avoid possible damage to the pump. In normal operation, the concentration unit would be operating as an integral part of the oxygen-regeneration system. The CO₂ collected in the accumulator would thus be passed through the regulator (Item 19) at a regulated pressure slightly above 5 psig and directed into the CO₂ reduction unit. A pressure-relief valve on the accumulator relieves at 60 to 65 psig.

In the vacuum mode of operation, the CO₂ transfer pump runs only to purge the bed of residual air. The pump is then shut off and the canister exposed to a vacuum sink through the space vacuum valve (Item 14) and the desorbing CO₂ is dumped to vacuum.

The unit cycle is 80 minutes with both silica gel and zeolite beds on a 40-minute half-cycle although staggered from each other. Information display and unit control are provided through a performance and control panel, shown in Figure 6.2-15. Also shown in Figure 6.2-15 is a Beckman electrolytic hygrometer and sampling pump used to monitor the moisture content of the air entering the zeolite beds. It is desirable that this moisture content be maintained below 100 ppm to avoid preferential adsorption of water on the zeolite, thus reducing CO₂ adsorption capacity. A backlighted schematic of the system has been included as a part of the control panel. Operational lights behind the schematic provide visual evidence of the cycling action of the system elements and the cycle time of each component.

Component Description. The process air enters the unit through a four-way butterfly valve. To reduce heat transfer across this valve, since one side contains cool incoming air and the other side has hot air leaving the desorbing silica gel bed, the butterfly of this valve is made of teflon. An identical valve is provided at the discharge of the silica gel canister. The valves are operated in unison through a splined shaft connecting both valves. Valve actuation is provided by a 28-vdc rotary actuator with internal limit switches to limit travel in each direction.

The silica gel canister contains Davison Chemical Company 05-08-08-2337, Grade H, 6-16 mesh beads. Heating and cooling of these beds for the desorbing or adsorbing function are accomplished by the process-air stream.

The heat exchangers used in this unit are plate-fin heat exchangers similar to those being developed for the Apollo-LEM vehicle. The process air enters and leaves the zeolite canisters through four-way vacuum-ball valves specifically developed by Hamilton Standard Division of United Aircraft for this application. These valves are also operated in unison through a splined shaft connecting both valves. Valve actuation is provided by a 28-vdc rotary actuator that contains limit switches to limit travel in each direction. In addition, a centering switch is provided to enable driving the ball valves to a 45-degree closed position to seal the canisters during standby or shutdown. The zeolite used was 8-12 mesh beads, 5A effective pore size, Ca absorbent, MIL-D-3716A, Grade M, Type 2, 522-08-05-215, purchased from Davison Chemical Company, Baltimore, Md.

Heating and cooling of the zeolite beds are accomplished through use of coils embedded within the canister. Hot or cold DC-331 fluid is passed through the coils to effect the desired temperature control. The heat-transfer coil is a complex coil of 3/8-inch tubing closely spaced to reduce zeolite-bed temperature transients. Figure 6.2-16 shows this arrangement.

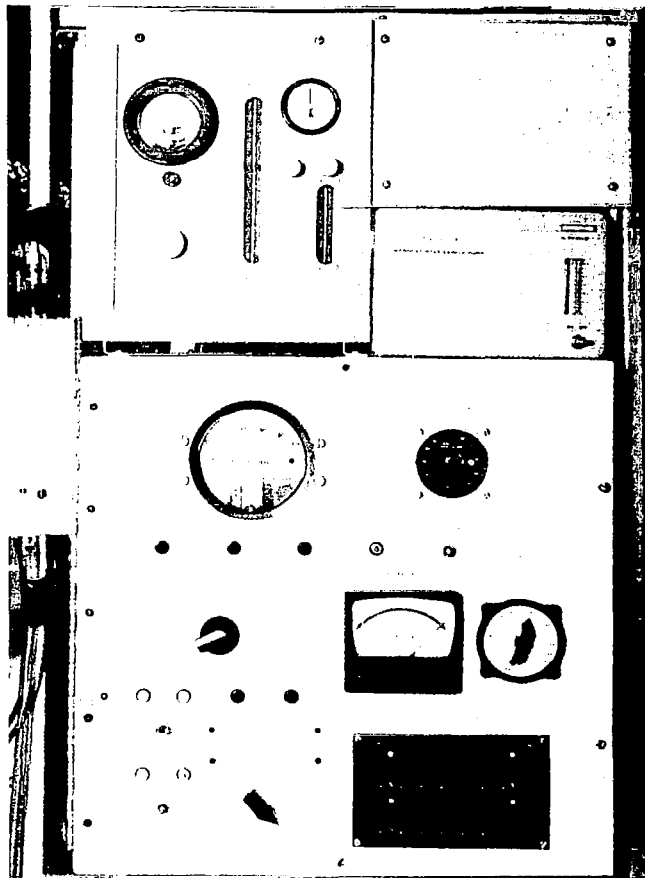


Figure 6.2-15. Electrolysis Unit Performance Panel

After leaving the zeolite canister, the process air passes through a diverter valve that directs the air through the liquid-to-air heat exchanger, if the air is to be heated, or acts to bypass the heat exchanger if the silica gel bed has been sufficiently heated. The flapper in this valve is made of teflon to reduce friction forces. Flapper actuation is through use of a 28-vdc solenoid with a locking feature.

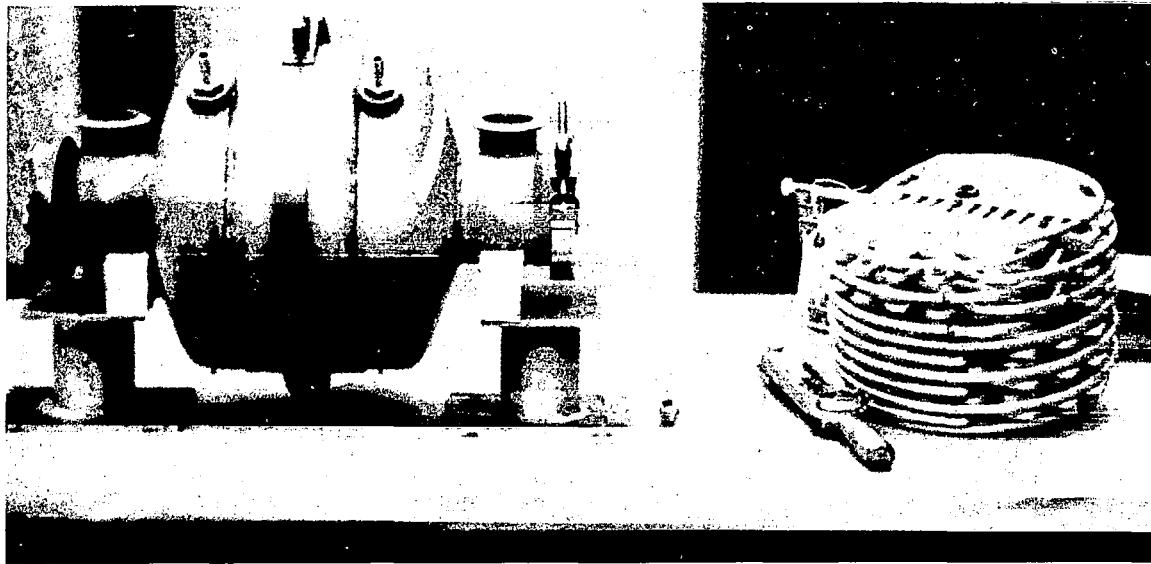


Figure 6.2-16. CO₂ Concentration Unit Zeolite Canister

Because of the requirement that this unit incorporate thermal desorption with vacuum desorption as an alternate mode, a space-vacuum valve was provided. As the CO₂ is desorbed from the zeolite bed, it passes out of the canister and through this space-vacuum valve. If thermal desorption is being used, the valve is positioned so that the CO₂ is drawn into the CO₂ transfer pump and delivered to the accumulator. If vacuum desorption is used, however, the valve is positioned (on a cyclic basis) to direct the desorbing CO₂ to the vacuum sink. This valve is a three-way vacuum-ball valve developed specifically for this application.

Some of the system components are shown in Figures 6.2-17 and 6.2-18. Because of the high system temperatures at which this unit operates, most of the components have been insulated to prevent personnel injury and also to minimize energy requirements by reducing undesirable heat transfer. A heat shield was also provided with the unit to prevent personnel injury. Because of the desire to provide maximum accessibility for repair, maintenance, and instrumentation installation, this item was removed from the unit.

The cyclic functions of the unit are controlled through a timer motor and a cam train that provide sequenced actuation of electrical switches. This unit is mounted within the control panel with the shaft and a pointer protruding through the forward face of the panel. An indicator has been installed so that as the pointer rotates with

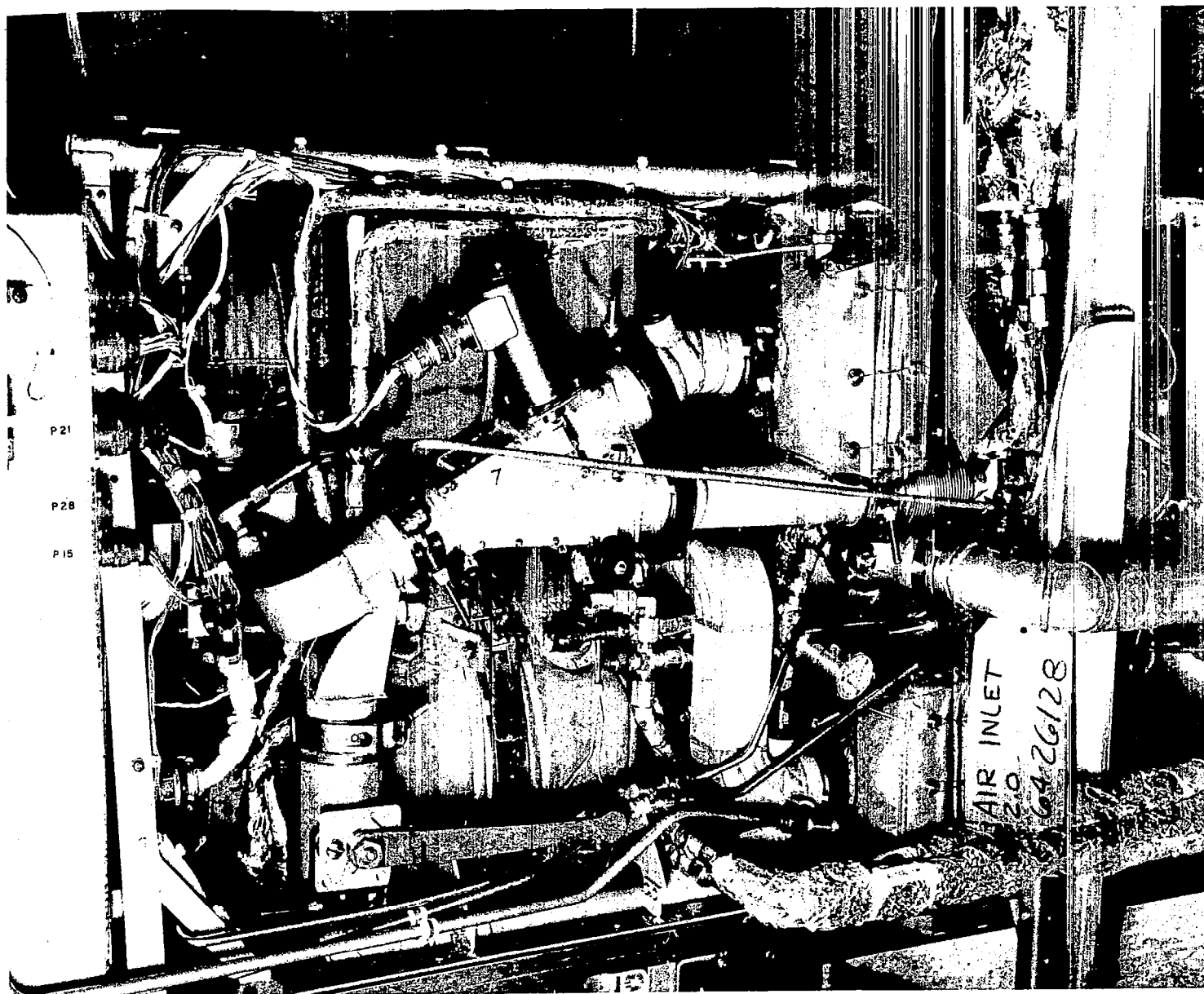


Figure 6.2-17. CO₂ Concentration Unit Right Side View

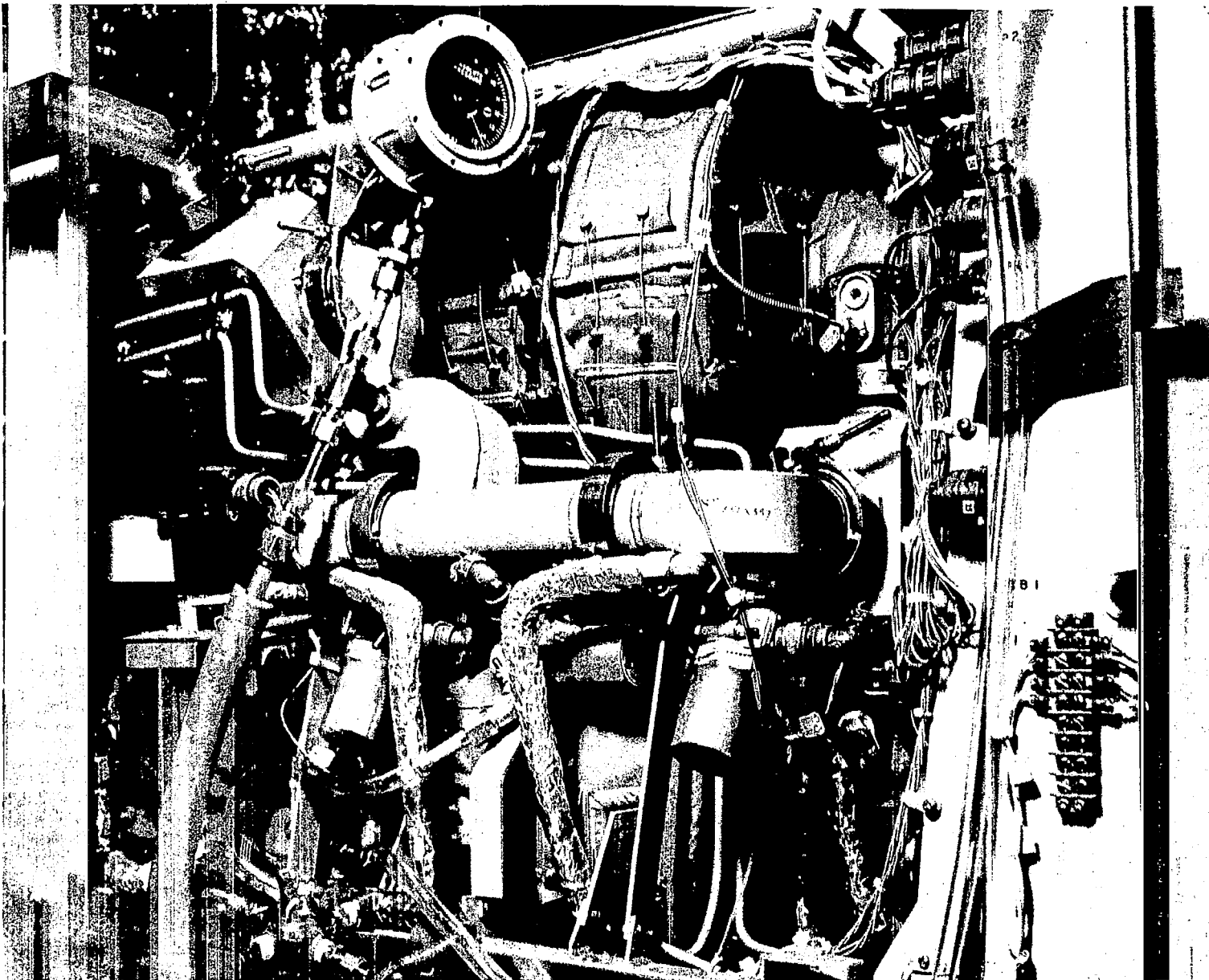


Figure 6.2-18. CO₂ Concentration Unit Left Side View

the timer-motor shaft, an indication is obtained that defines which silica gel bed and zeolite bed are in the adsorbing or desorbing mode and the time remaining in that mode. This is particularly useful in ascertaining the time to end a cycle and also to determine which silica gel bed to start dry-down on so that proper sequencing is obtained when the unit is switched into the auto mode. Figures 6.2-19 and 6.2-20 are views of the interior of the control panel.

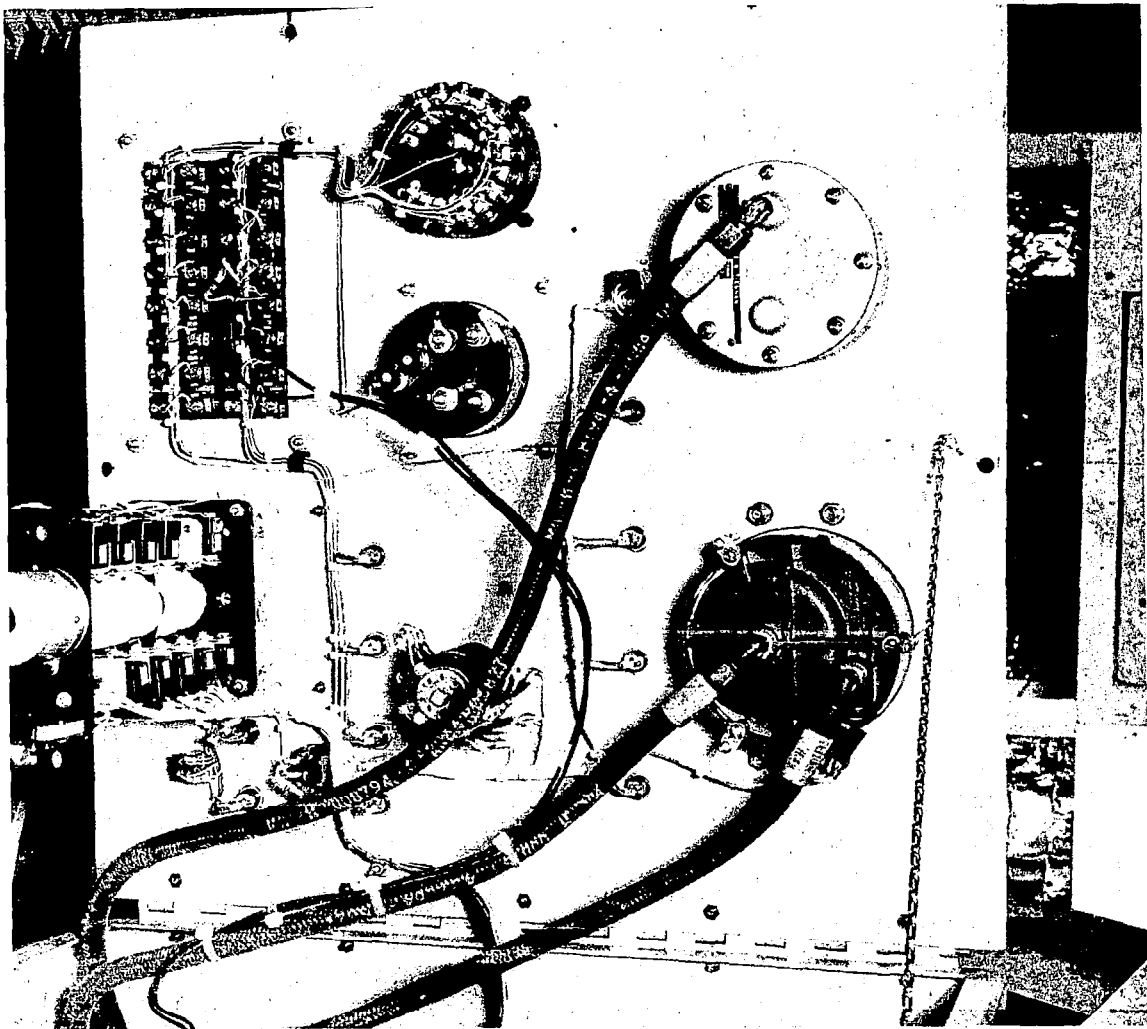


Figure 6.2-19. CO₂ Concentration Unit Control Panel Door

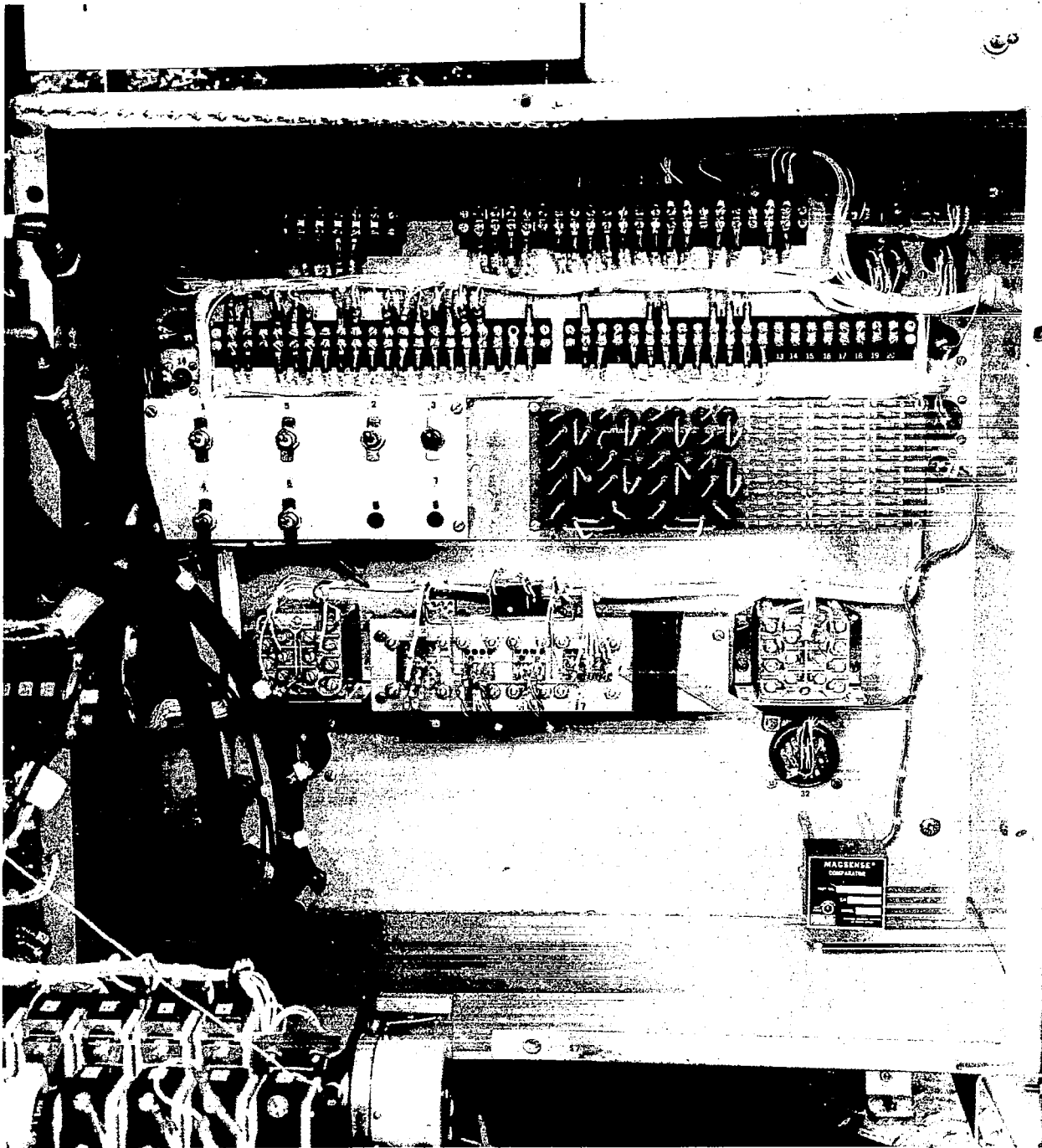


Figure 6.2-20. CO₂ Concentration Unit Control Panel Interior

6.2.2.2 CO₂ Reduction Unit

Design and Operation. Final design of the reduction unit was proven during the demonstration tests conducted during the week of 12 July 1965. The functional relations of the various components of the unit are shown in Figure 6.2-21. The reduction unit is the element of the oxygen-regeneration system that processes the CO₂ from the accumulator of the concentration unit, reacting it with H₂ from the electrolysis unit to form water. The water is delivered to a collection tank, where it is added to the inventory of the water-reclamation system. Oxygen regeneration is completed when reclaimed water is introduced to the electrolysis unit and the oxygen content is again released to the cabin.

The unit utilizes a Bosch reaction for the primary mode of operation, reducing the carbon in the CO₂ feed gas to a dry powder that is continuously collected in a low-temperature cloth bag that can hold several days' accumulation of carbon. A Sabatier reactor provides a backup mode of operation, producing methane, which is vented to vacuum, and water. The water appears as steam in both reactions, and a condenser and porous-plate water separator are provided to remove water from the unit. The condenser is cooled by aqueous propylene glycol from an external cooling and pumping unit.

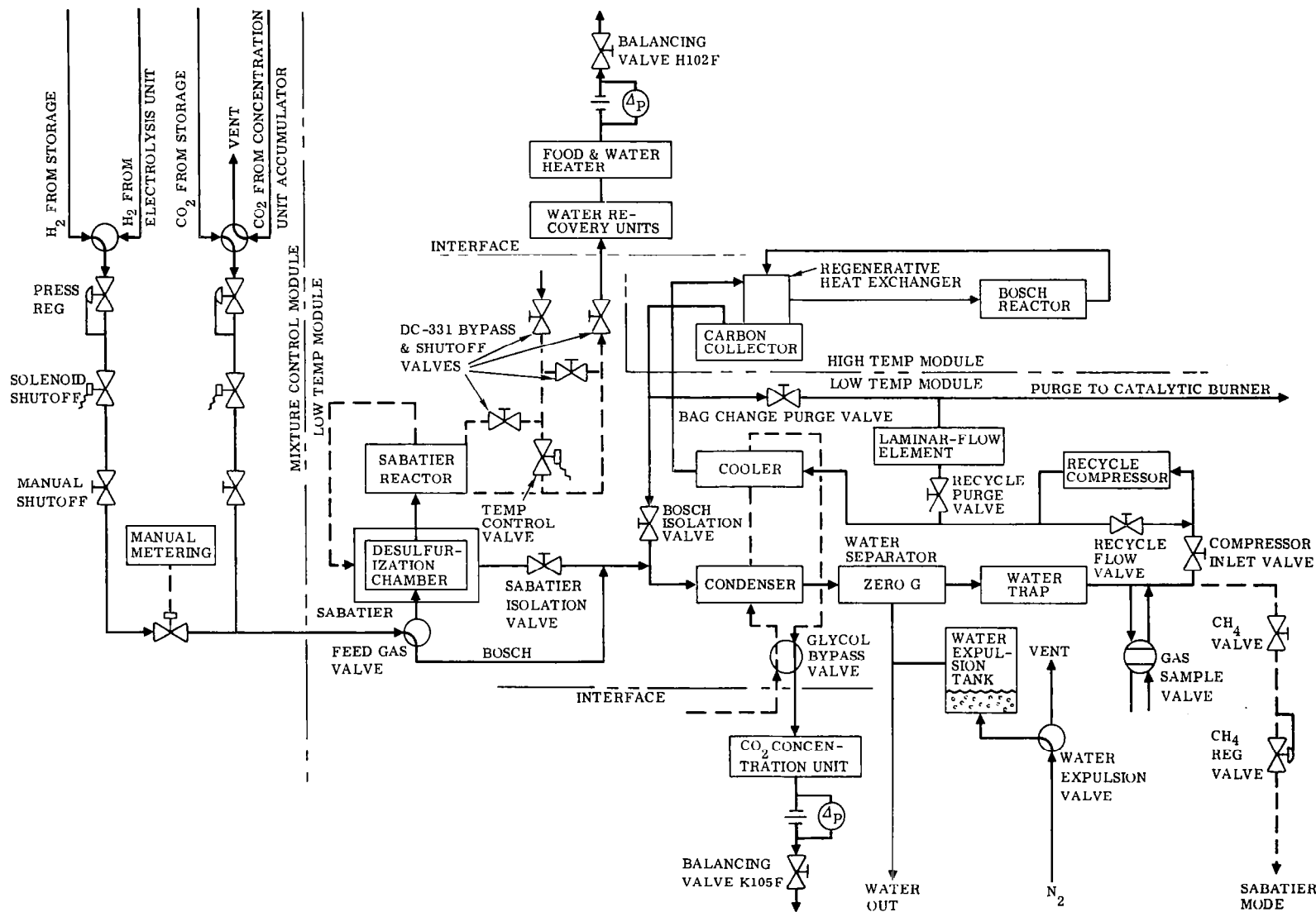
Gases are recycled through the Bosch reactor by a positive-displacement compressor, and most of the heat in the reactor-discharge gases is recovered in a regenerative heat exchanger and returned to the reactor. Feed gas makes but one pass through the Sabatier reactor.

The Bosch reactor is heated electrically by 600-watt auxiliary external heaters and an internal main-cartridge heater that is normally set to 200 watts. Temperature control is accomplished with the external heaters that trip to half power at set point temperature, nominally 1240°F.

The Sabatier reactor is preheated with DC-331 from the heating and pumping unit and is automatically cooled by the same fluid at the Sabatier set point temperature, nominally 500°F.

Purge gas can be vented to the cabin air catalytic burners if they are up to operating temperature. A small purge flow is used to adjust the composition of recycle gases when operating in the Bosch mode or to vent N₂ to compensate for feed-gas impurity. A high purge rate is employed to flush the system with CO₂ prior to changing the carbon-collection bag.

Installation. The reduction unit is located in the laboratory module of the test bed, opposite the air lock and between the concentration unit and water-recovery units (Figure 6.2-22). The most prominent feature of the unit is the long, vertically installed, regenerative heat exchanger.

Figure 6.2-21. CO₂ Reduction Unit Flow Schematic

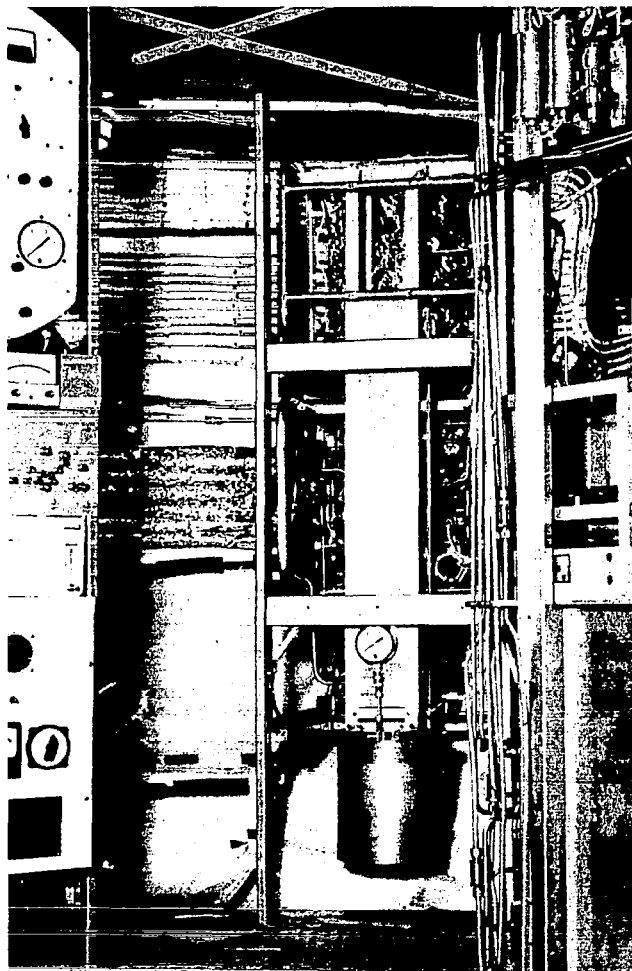


Figure 6.2-22. CO₂ Reduction Unit Installation

The unit consists of four packages: mixture-control, low-temperature, high-temperature, and the control panel.

The feed-pressure regulators are located in the mixture-control package; manual shutoff valves are mounted on the front of the package; and two feed-gas selector valves are mounted behind the package to permit selection of feed gas from storage bottles or from the concentration and electrolysis units.

The Sabatier reactor, desulfurization chamber, condenser, water separator, water trap, and recycle compressor are located in the low-temperature package (Figure 6.2-23). Manual control valves are mounted in a valve-display panel on the front of the package, and the DC-331 and coolant bypass valves are on the back of the package (Figure 6.2-24).

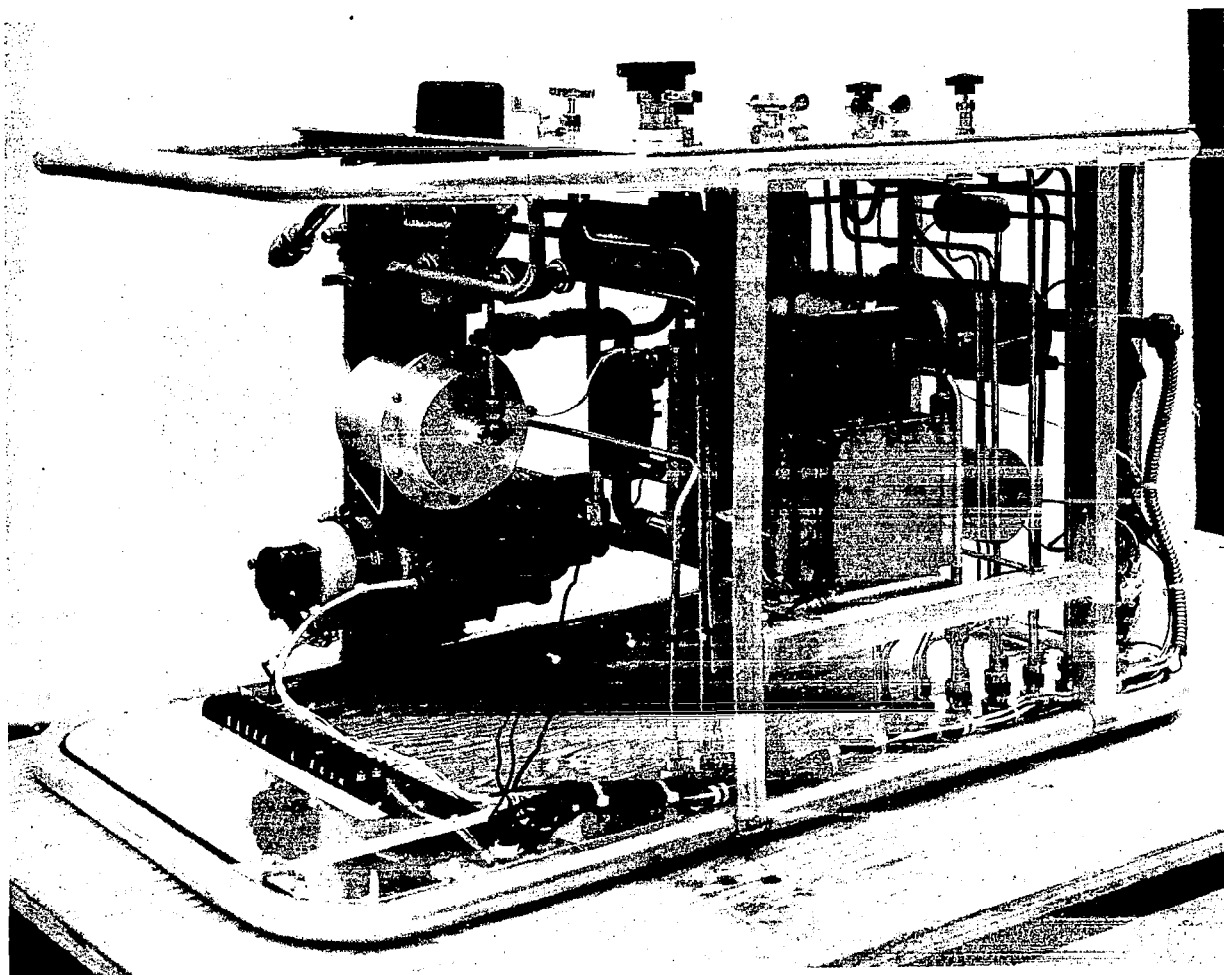


Figure 6.2-23. CO₂ Reduction Unit Low-Temperature Package

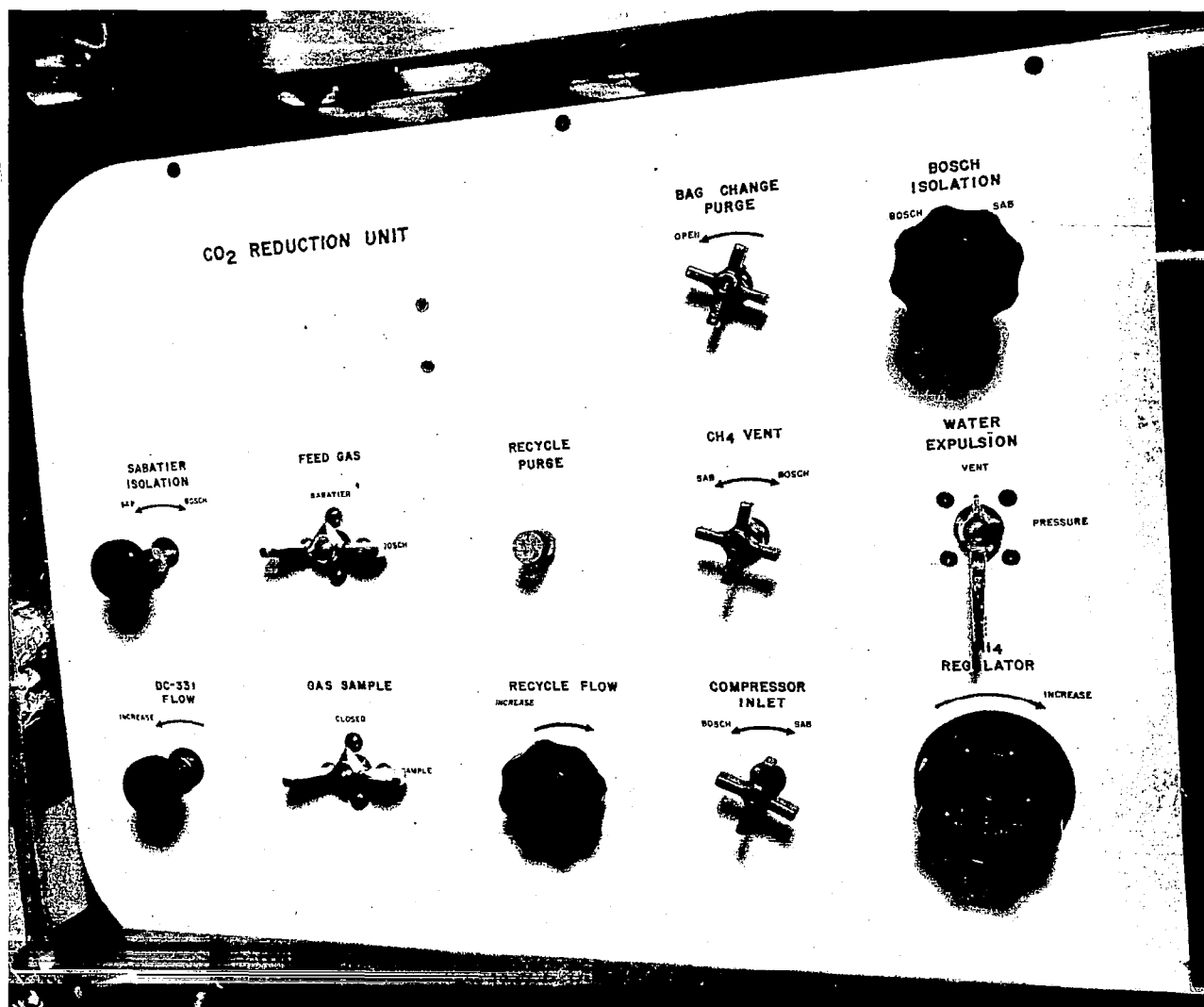


Figure 6.2-24. CO₂ Reduction Unit Valve Display Panel

The Bosch reactor and regenerative heat exchanger are in the high-temperature package (Figure 6.2-25). Carbon is loosened and removed from the iron catalyst plates by rotating the plates against a set of stationary fingers, visible when the reactor is disassembled for inspection (Figure 6.2-26).

The control panel contains electric on-off switches, a manual mixture control, power controls for the main and auxiliary heaters, and instrumentation (Figure 6.2-27). The system switch is on the on-board status panel, and circuit breakers are on the ground control console.

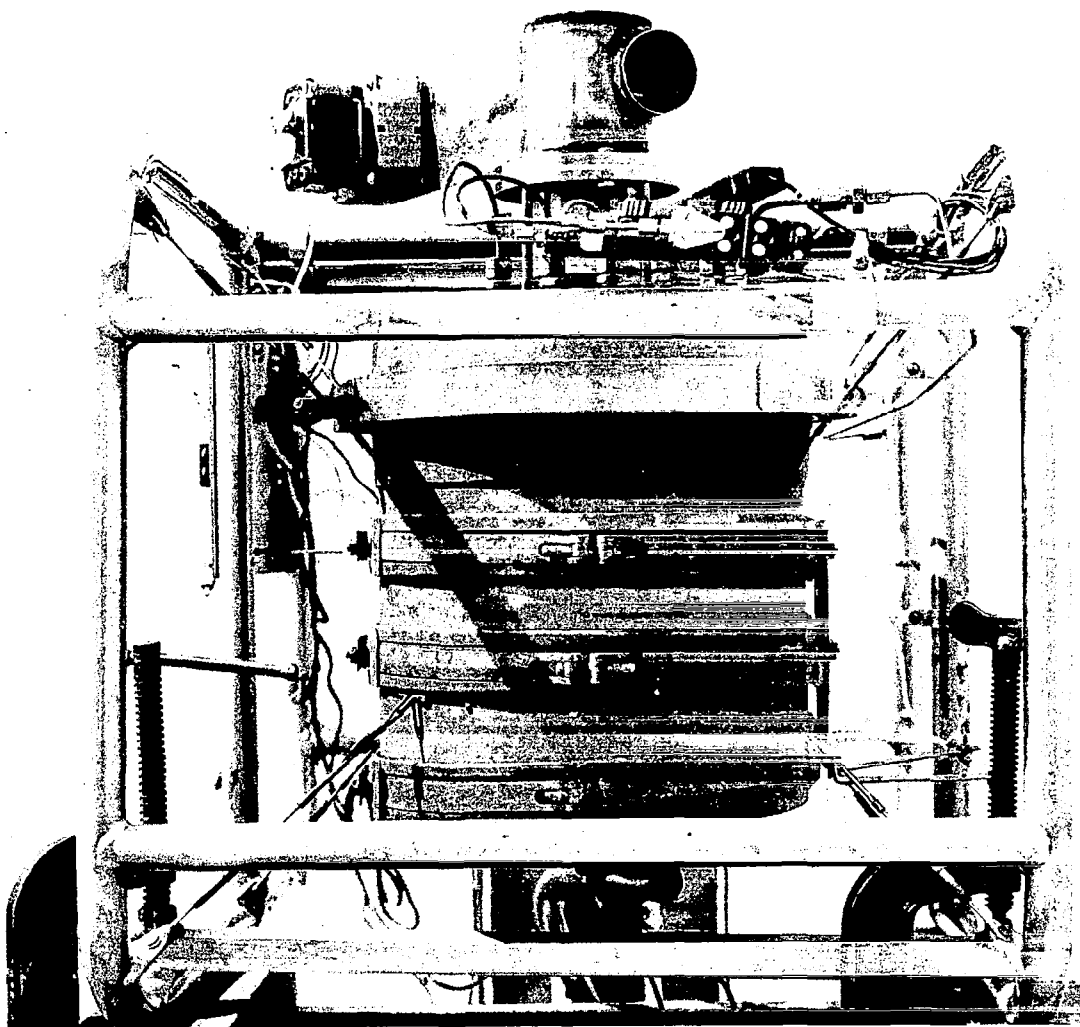


Figure 6.2-25. CO₂ Reduction Unit High-Temperature Package

Bosch Operation. Warmup in Bosch mode is accomplished in about 12 hours with the electric heaters. CO₂ is pumped through the recycle loop to prevent overheating of the heaters and to bring the regenerative heat exchanger up to operating temperature. The condenser is supplied with cooling fluid during warmup to keep the water separator from drying out and to maintain a normal inlet temperature to the recycle compressor. The unit requires no adjustment except step reductions in main-heater power as the reactor comes up to temperature.

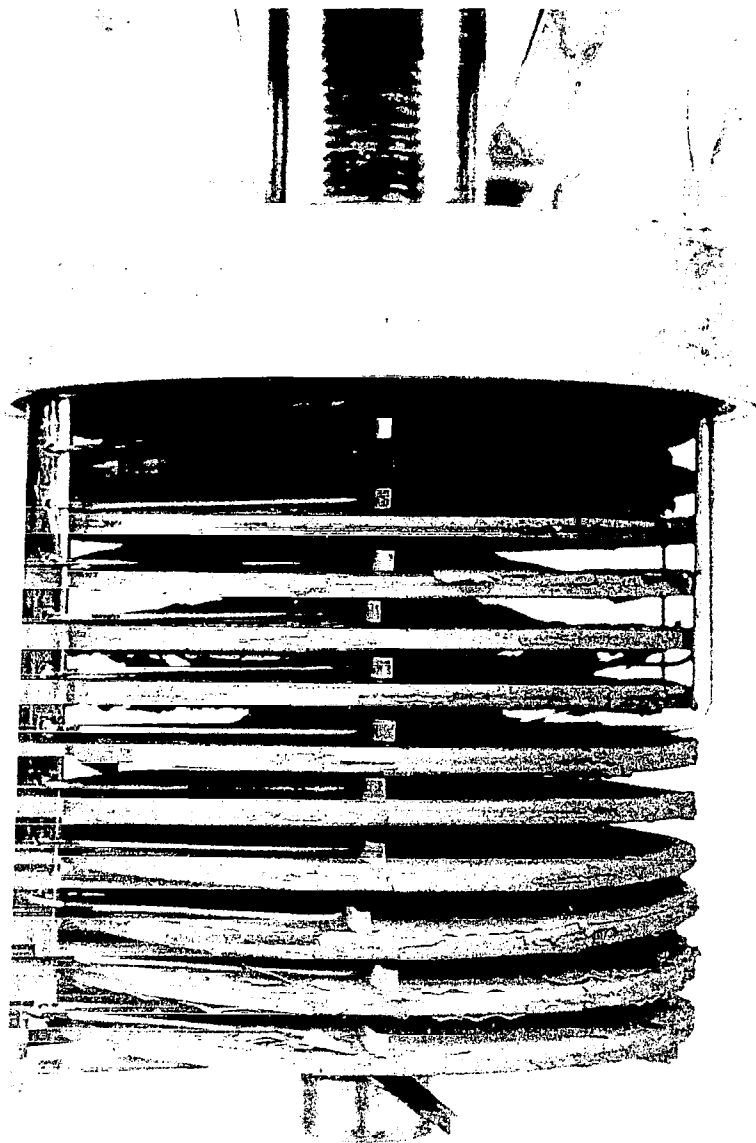


Figure 6.2-26. CO₂ Reduction Unit Bosch Reactor Catalyst Plates

A strong Bosch reaction begins as soon as hydrogen is added to the CO₂ in the recycle loop if the reactor temperature is 1200°F or more. The reaction rate builds up rapidly if the loop is purged with H₂ for a few minutes before adjusting the feed flow to a stoichiometric mixture. There is no transition between start and steady-state running except to adjust the reactor temperature set point to obtain the desired process rate.

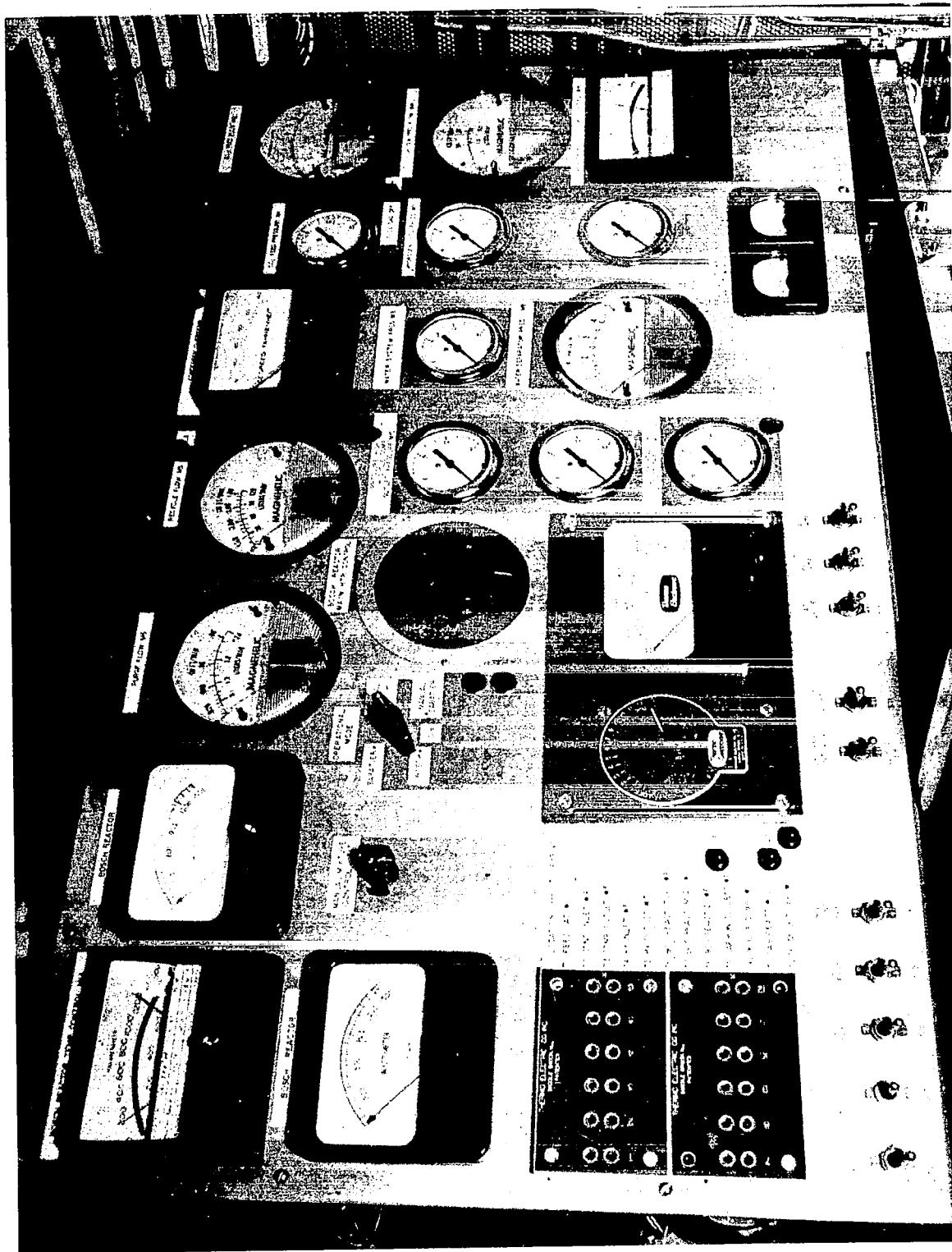


Figure 6.2-27. CO₂ Reduction Unit Control Panel

Sabatier Operation. Warmup in the Sabatier mode is accomplished in about 1 hour, using hot DC-331 from the process-heat circuit. The condenser is supplied with cooling fluid to precool it and keep the water separator from drying out when the feed gas is turned on.

A mild Sabatier reaction begins as soon as hydrogen is added to the CO₂ if the reactor temperature is the maximum attainable with the hot DC-331, approximately 340°F. The reaction is exothermic, so that the reactor temperature increases if the heat is conserved by shutting off the DC-331 flow. The starting technique consists of slowly and periodically increasing the feed-gas rate as the temperature increases. There is no transition between start and steady-state running except to adjust the reactor-temperature set point to obtain the desired process rate.

Design and Operating Details. Development of the unit is documented in Redesign of the CO₂ Reduction Unit, General Dynamics Convair Report 64-26229, 12 August 1965; and complete operating instructions are given in Handbook of Operating Instructions, General Dynamics Convair Report 64-26230, 6 August 1965.

Drawings and applicable documents are tabulated in Master Document Summary, General Dynamics Convair Report 64-26233, 30 September 1965.

6.2.2.3 Electrolysis Unit. The unit is designed around a basic electrolysis cell that converts incoming water to H₂ and O₂. This cell consists of two current-carrier assemblies and one rubber electrolyte spacer. The current-carrier assemblies are similar to those used in the G. E. Gemini fuel cells and consist of a metal current carrier, a layer of platinum black for the electrode, and an ion-exchange membrane that serves as a gas-liquid barrier. The membranes of two current-carrier assemblies are placed face-to-face against a rubber spacer to form the H₂SO₄ electrolyte chamber of the cell. The rubber spacer supports a small stainless-steel tube that serpentine through the electrolyte chamber for cell cooling with propylene glycol.

Sixteen of these basic cells are stacked and compressed by fiberglass end plates that are bolted together. The compression provides a leak-tight electrolyte chamber and also assures good electrical contact from one cell to the next. Passage of direct current through the stack results in formation of H₂ and O₂ within the current-carrier assemblies. These gases leave the cells through small tubes and feed into manifolds exterior to the stack. Similarly, the water feeds to the cell through a manifold and small tubes.

The O₂ and H₂ gases contain small amounts of acid that are carried across the membranes in the electrolysis process. Therefore, these gases are passed through cooled liquid separators just outside the stacks. The separators remove the acid and condense and remove excess water vapor in the output gases. The liquid stripped from the gases is fed directly back into the cell electrolyte chambers. The separators utilize microporous-ceramic plates in which the capillary forces sustain the zero-gravity gas-liquid interface.

The overall electrolysis unit consists of three identical stacks as described above. Each stack, including manifolds and separators, is enclosed in a metal housing to form one module of the unit (designated A, B, or C). The module housings are pressure tight and contain nitrogen to provide an inert atmosphere for the stack. An N_2 over-pressure is maintained to minimize the possibility of O_2 and H_2 mixing if leaks develop within the modules.

The three modules are mounted on a frame that contains the fluid manifolds, valves, instrumentation, wiring, and electrical controls that are needed to integrate and control the module functions and make-up unit. A flow schematic is shown in Figure 6.2-28, and a complete system diagram and parts list are shown in Convair Drawing 64-26163. Only module A is shown in Figure 6.2-28. The valves with an A suffix, such as MV-5A, are also used on modules B and C. The valve functions are summarized in Table 6.2-I, and some of the valve locations are shown in Figures 6.2-29 through 6.2-31. The performance panel of the unit is shown in Figure 6.2-32. Refer to the unit wiring diagram, Convair Drawing 64-26173, for details of electrical-switching functions, electrical gages, warning lights, etc.

The detailed description of the unit in the following sections refers primarily to the drawings and figures mentioned above. The GE drawings of the unit may also be referred to for more detail. A complete list of these drawings is contained in the Master Document Summary, General Dynamics Report 64-26233.

Water Feed Circuit. The unit receives water from the electrolysis-feed accumulator tank (AC-1), which is pressurized with N_2 to 9 psig. The water line is connected to the rear of the unit with a quick-disconnect coupling that shuts off the flow when uncoupled. The feed water passes through an adjustable regulator, where the pressure is reduced to 6.5 psig. Manual Valve RO-1 downstream of the water regulator can be used to restrict or shut off the water flow to all the modules. This valve is normally left full open during both operation and standby of the unit.

Solenoid 1 provides an automatic water shutoff if the unit pressures go out of tolerance. The shutoff is triggered by a pressure switch that senses the water pressure and closes Solenoid-1 if the water pressure exceeds approximately 7 psig. This prevents the water pressure from exceeding the O_2 and H_2 gas pressures, which are maintained at about 7.5 psig. Solenoid 1 automatically re-opens if the water-circuit pressure drops back below 7 psig. Solenoid 1 also closes if the pressure drops below 6 psig or if the H_2 , O_2 , or N_2 pressure drops below 5.5 psig. Then the unit shuts down by:

- a. Venting H_2 through Solenoid 3.
- b. Venting O_2 through Solenoid 2.
- c. Closing off the water supply through Solenoid 1 and thus allowing the water pressure to fall as the O_2 and H_2 are vented.
- d. Shutting off electrical power to the module cell stacks.

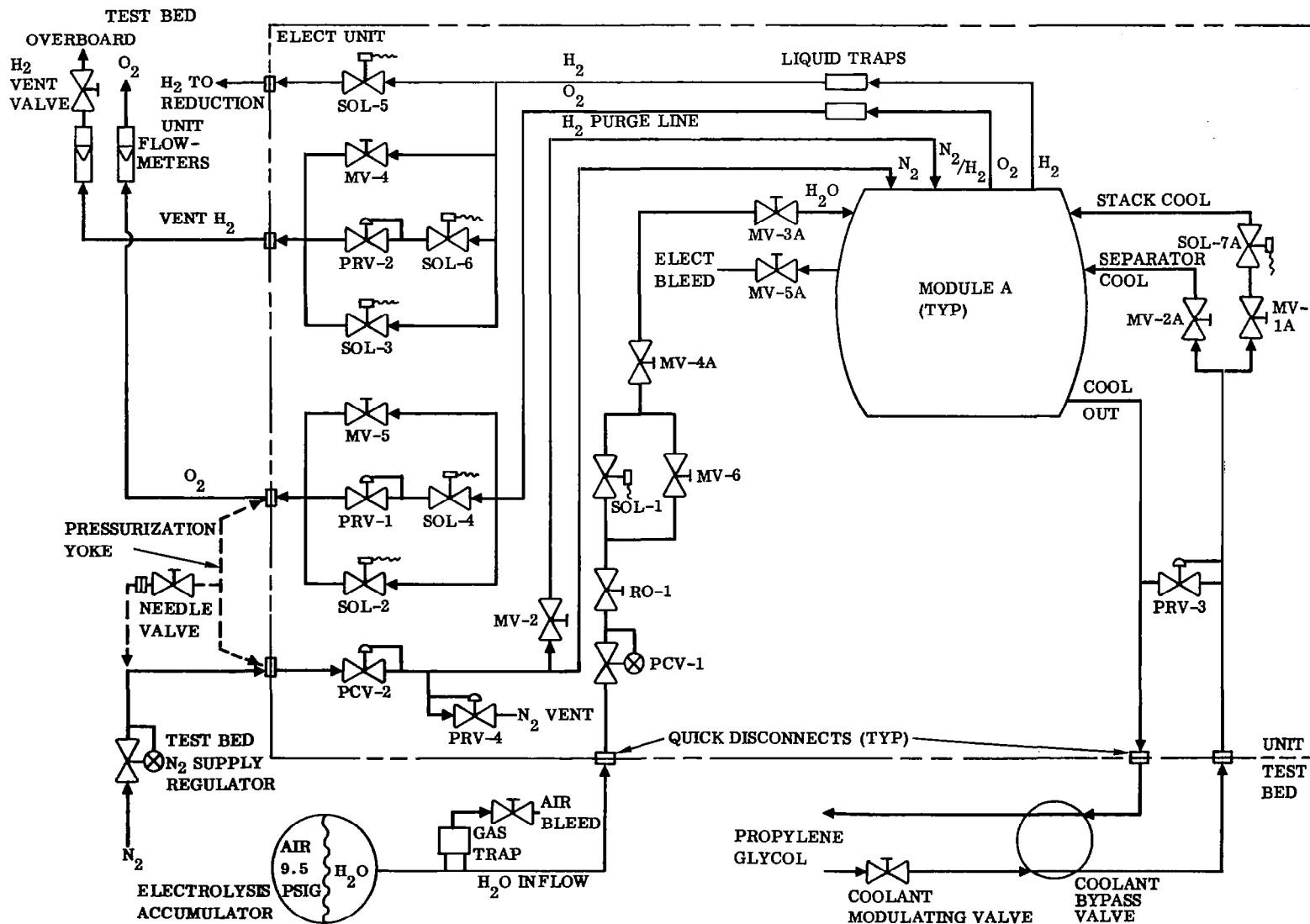


Figure 6.2-28. Electrolysis Unit Flow Schematic

Table 6.2-I. Electrolysis Unit Valve Functions

VALVE SYMBOL	VALVE TYPE	FUNCTION
PCV-1	Pressure Regulator	Controls feed water pressure to the modules.
PCV-2	Pressure Regulator	Backup control for N ₂ pressure to the modules.
PRV-1	Back Pressure Regulator	Controls module O ₂ pressure.
PRV-2	Back Pressure Regulator	Controls module H ₂ pressure.
PRV-3	Back Pressure Regulator	Limits unit coolant pressure differential.
PRV-4	Back Pressure Regulator	Relieves N ₂ overpressure.
MV-2	Manual Metering Valve	Connects N ₂ circuit to H ₂ circuit for purge and pressurization.
MV-4	Manual Metering Valve	Bypasses H ₂ regulator and vents H ₂ circuit.
MV-5	Manual Metering Valve	Bypasses O ₂ regulator and vents O ₂ circuit.
MV-6	Manual Metering Valve	Bypasses water shutoff solenoid valve.
RO-1	Manual Metering Valve	Meters and shuts off water inflow.
MV-1A, B & C	Manual Metering Valve	Modulates stack coolant flow.
MV-2A, B & C	Manual Metering Valve	Modulates wick transport coolant.
MV-3A, B & C	Manual Metering Valve	Module water feed shutoff at module.
MV-4A, B & C	Manual Metering Valve	Module water feed shutoff at unit.
MV-5A, B & C	Manual Metering Valve	Electrolyte bleed shutoff.
Sol-1	Solenoid Valve (NC)*	Automatic water feed shutoff.
Sol-2	Solenoid Valve (NC)	O ₂ high-pressure relief.
Sol-3	Solenoid Valve (NC)	H ₂ high-pressure relief.
Sol-4	Solenoid Valve (NO)	O ₂ low-pressure shutoff.
Sol-5	Solenoid Valve (NO)	H ₂ low-pressure shutoff to reduction unit.
Sol-6	Solenoid Valve (NO)	H ₂ low-pressure shutoff.
Sol-7A, B&C	Solenoid Valve (NO)	Module on-off coolant flow control.

*NC = Normally Closed

NO = Normally Open

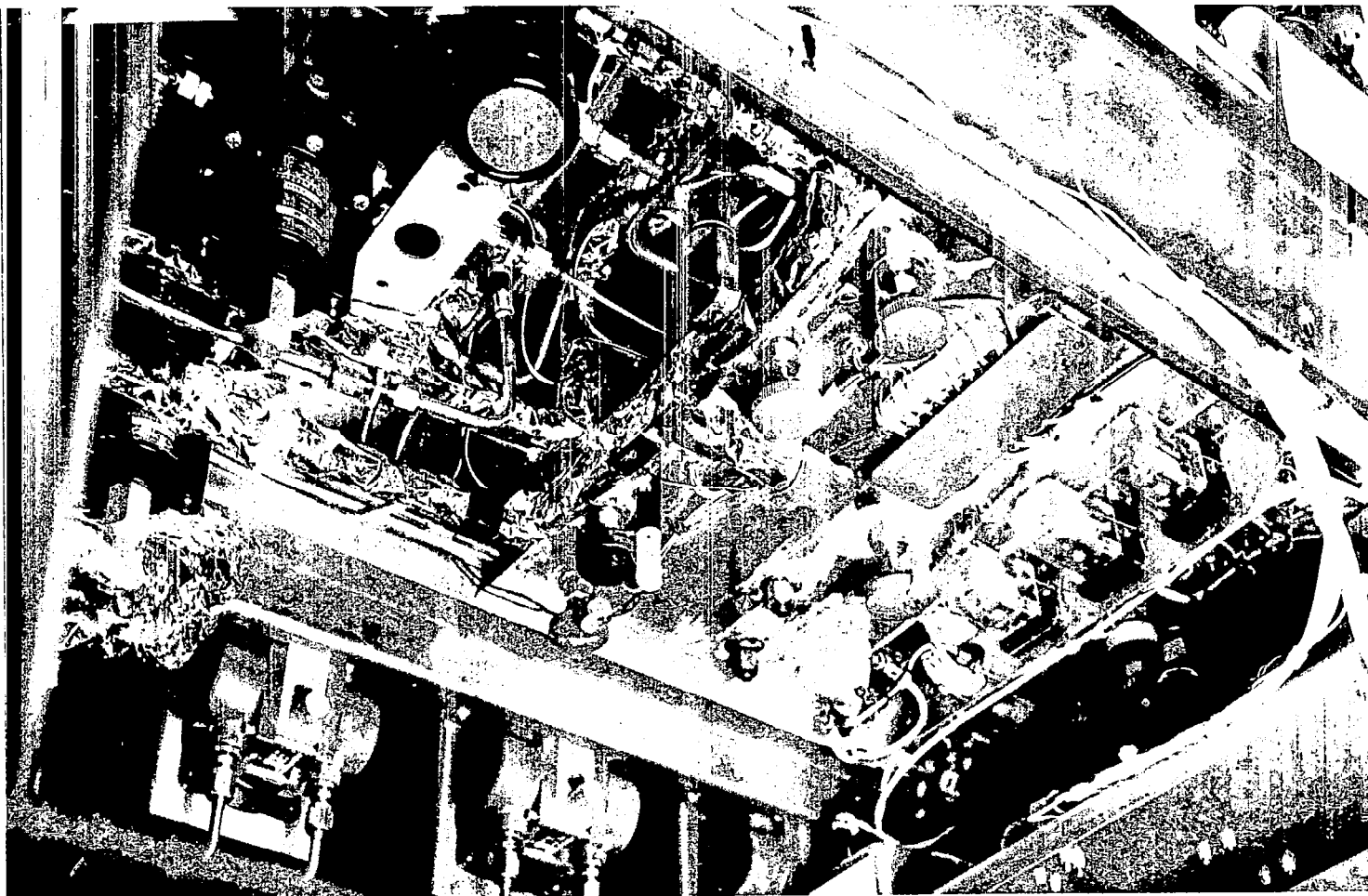


Figure 6.2-29. Underside of Electrolysis Unit

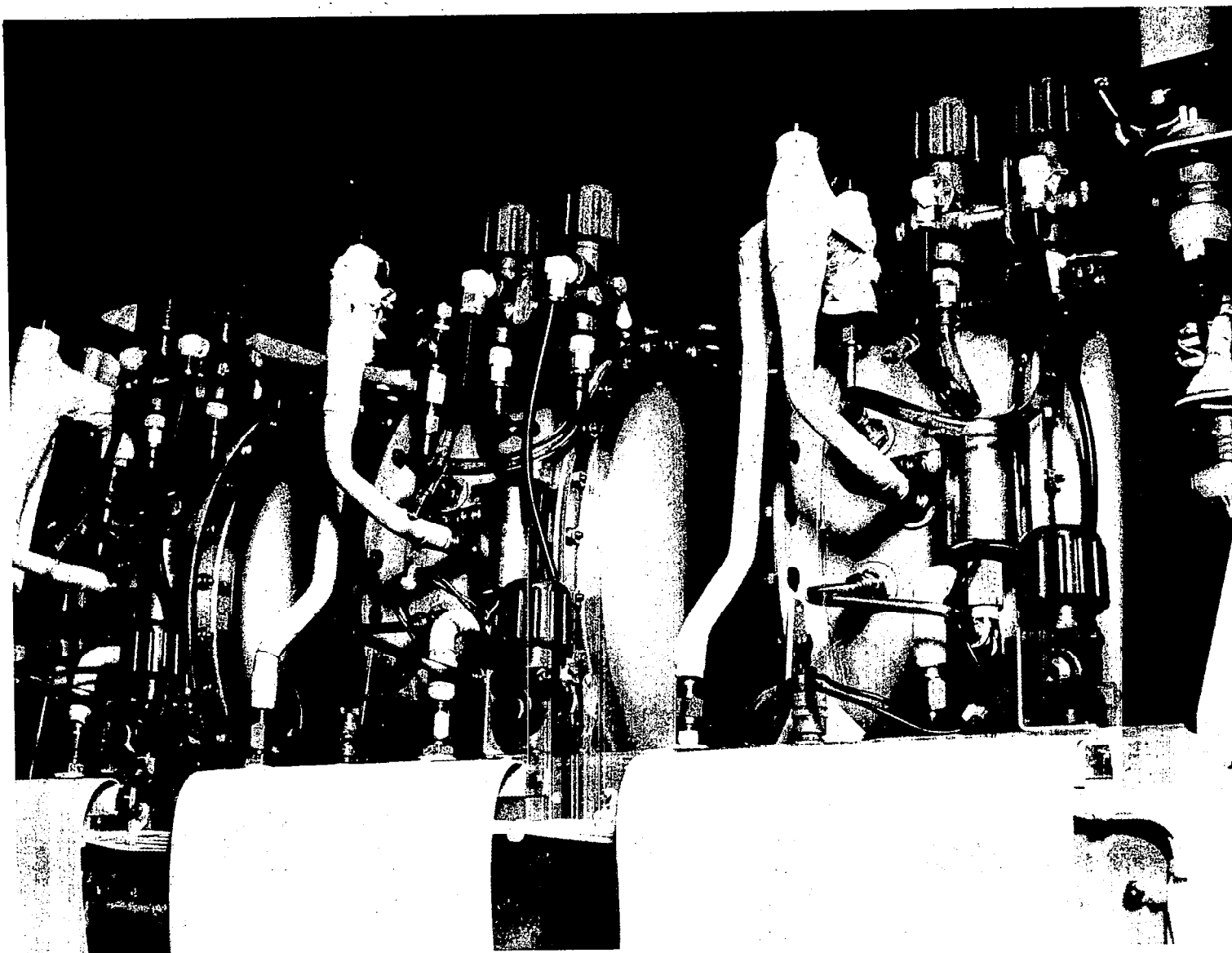


Figure 6.2-30. Electrolysis Unit Left Side

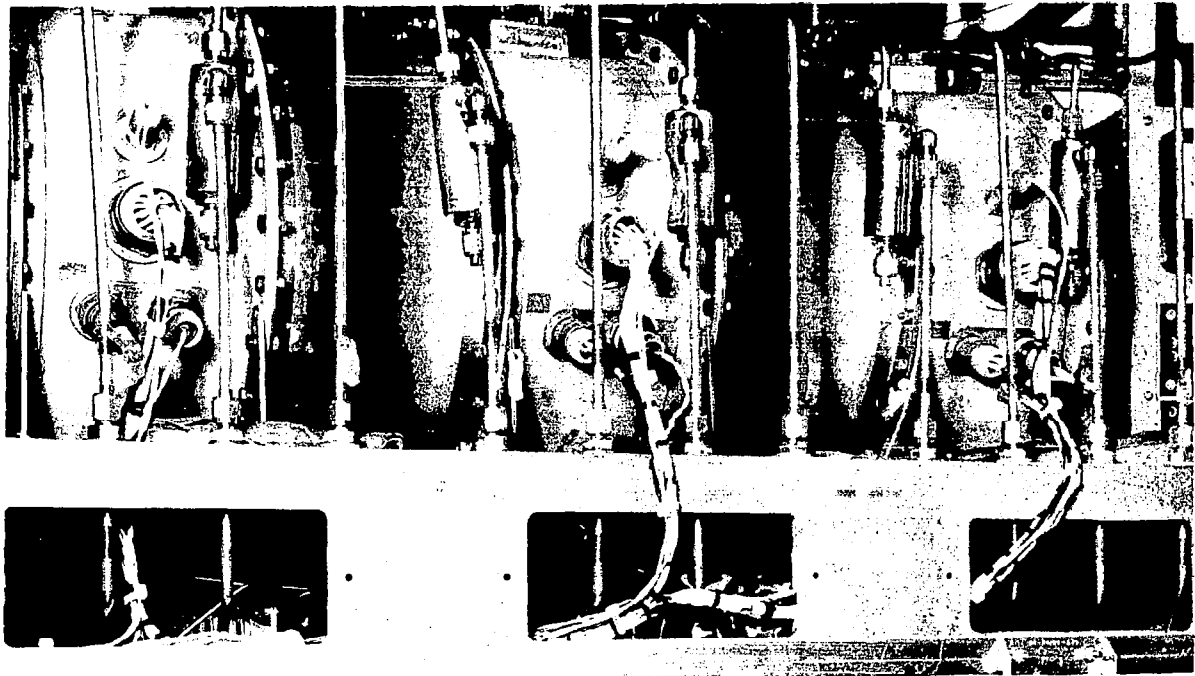


Figure 6.2-31. Electrolysis Unit Right Side

A manual bypass around Solenoid 1 is provided by Valve MV-6. This valve is used during unit startup.

The water-feed lines from the accumulator to Solenoid 1 and Valve MV-6 are 1/4-inch stainless steel. The manifold that feeds the individual modules is acid-resistant 1/4-inch polyethylene plastic. Valves MV-3A, B, and C and MV-4A, B, and C are

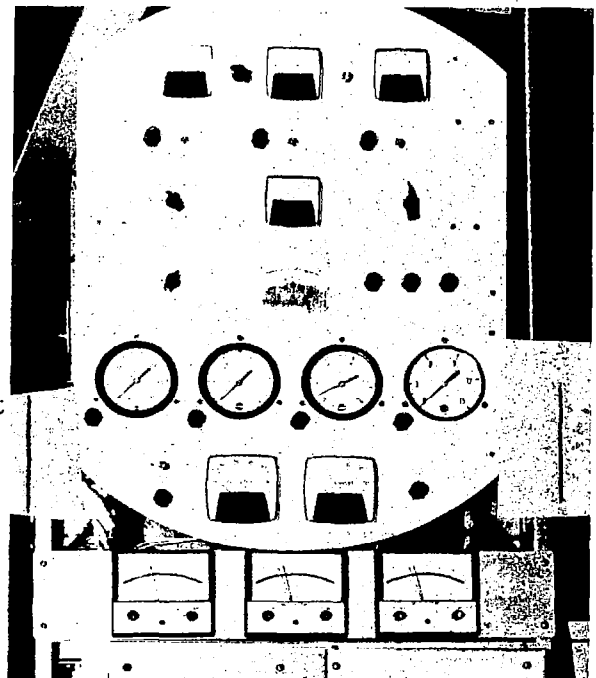


Figure 6.2-32. Electrolysis Unit Performance Panel

plastic. These valves isolate the module electrolyte circuits when the modules are removed from unit frame. The electrolyte lines within the modules are mostly tygon tubing, which is also resistant to sulfuric acid.

Coolant Circuit. The main coolant lines under the unit are 3/8-inch stainless steel. Relief Valve PRV-3 opens to bypass coolant around the unit if the unit differential pressure exceeds 7 psig. This valve was originally included to prevent starving units in series with the electrolysis unit if the latter became clogged. The electrolysis unit is now in a separate parallel cooling circuit and Valve PRV-3 is unnecessary.

The coolant lines leading to the individual modules are 1/4-inch stainless steel. The inlet line splits into one circuit for stack cooling and a second circuit for separator cooling. Two manual needle valves control the relative coolant-flow rate through the two circuits on each module. In addition, a solenoid valve (7A, B, or C) provides on-off coolant-flow control to the stack. The solenoid is actuated by a stack temperature-thermocouple signal, which is fed through a controller and a readout meter. The meters are shown in the lower portion of Figure 6.2-32. The meters include adjustment knobs for the temperature set point and an automatic high-temperature cutoff. The coolant lines within the modules are thick-walled tygon to withstand the coolant-circuit pressures.

Nitrogen Supply. Nitrogen for unit pressurization comes from the main test-bed N_2 supply line through an adjustable N_2 supply regulator. The unit has an internal N_2 regulator (PCV-2), which is used as a backup, set at about 9.5 psig, which is slightly higher than the pressure setting on the supply regulator. Relief Valve PRV-4 opens if the stack housings become overpressurized with N_2 . Bleed screws are located on top of the housings for manual venting of N_2 .

The N_2 circuit provides for purging the H_2 circuit with N_2 during unit startup and shutdown. Manual Valve MV-2 is opened during these times, and N_2 flows through the H_2 circuits of the individual cells and out the H_2 vent line.

H_2 and O_2 Output-Gas Circuits. The H_2 and O_2 output-gas circuits are similar. The output gases leave the cell stack and flow through six identical zero-g gas/liquid separators and out of the stack housings. Before the gases enter the unit manifolds they pass through 1-g liquid traps (Figure 6.2-28), which act as backups to the zero-g separators.

The O_2 and H_2 manifold and module pressures are controlled by back-pressure regulators PRV-1 and PRV-2 respectively. These regulators are accessible under the rear of the unit for adjustment. (See Figure 6.2-29.) Solenoid 4 and Solenoid 6 act as safety shutoffs if the back-pressure regulators fail to open. These valves are actuated by pressure switches if the output-gas pressures drop to about 6.5 psig. In the H_2 output circuit Solenoid 5 is actuated by the same signal that actuates Solenoid 6. Hence, if the H_2 pressure drops too low, H_2 flow to the reduction unit is shut off.

Solenoid 3 and Solenoid 2 relieve the H₂ and O₂ gas pressures if the regulators fail to shut. These valves open at about 8 psig. Manual valves MV-4 and MV-5 bypass the output-gas regulators and solenoid valves. These valves are used during unit startup and shutdown.

Electrical Circuitry and Instrumentation. The direct-current voltage applied to the stacks for electrolysis is separate from the direct-current voltage for the control circuitry since the stack requires up to 33 volts but the control components are rated at 28 volts. The control-circuit power is taken from the main test-bed 28-volt supply. A separate supply that can be adjusted to maintain a constant stack current and therefore a constant gas output is used for the stacks. The LINE VOLTAGE and TOTAL CURRENT meters on the performance panel measure the stack voltage and current.

A resistor bank is used to limit initial startup current to the modules. Initially, the stack cells are all unpolarized and draw in excess of 15 amperes if full voltage is applied. Partial voltage is therefore applied by opening the SHORTING SWITCH on the performance panel thereby switching the resistors into series with the stacks. Full voltage is applied by closing the shorting switch, which shorts out the resistors. The resistor bank is used with only one module at a time.

Continuous full voltage to the stacks is applied through the module power switches, which contain circuit breakers that open at 12.5 amperes. If the circuit breakers open or power otherwise is removed from the stack, the red warning lights beside the module power switches are turned on.

Any cell voltage within the unit can be read out on the performance panel CELL VOLTAGE meter. The MODULE SELECTOR switch and CELL SELECTOR switch are used to select the desired cell.

The modules contain thermal switches that cut off power to an overheated module. If this happens, the module temperature-alarm light and the module power-alarm light go on indicating that the module has successfully shut down. A backup overtemperature cutoff is provided by the module controller-readout units. This cutoff also lights the alarm lights.

The performance panel contains pressure gauges for the unit H₂, H₂O, O₂, and N₂ circuits. Pressure switches in these circuits activate red warning lights to show whenever pressures are out of tolerance. These go on simultaneously with the solenoid valves that function to automatically maintain the proper unit pressures.

For further details of the electrical circuitry, refer to Convair Drawing 64-26173.

Summary of Automatic Functions. As described in the preceding paragraphs, the unit automatically functions to correct out-of-tolerance temperature and pressure conditions. A summary of these functions is given below.

<u>EMERGENCY CONDITIONS</u>	<u>UNIT ACTION</u>
High module temperature	Electrical power shuts off to the hot module.
Low N ₂ pressure or low H ₂ O pressure	Power removed from the modules, H ₂ and O ₂ gas circuits vent, and the water-shed solenoid shuts.
Low H ₂ or O ₂ pressure	Flow to the normal O ₂ or H ₂ output-regulator valves shuts off.
Complete loss of O ₂ and H ₂ pressure	Power to the stacks cuts off, water feed stops, and the H ₂ and O ₂ circuits vent.
High H ₂ or O ₂ pressure	The overpressurized circuit vents until the pressure returns to normal.
High H ₂ O pressure	The water feed stops.
High module current	The high module shuts down.
High N ₂ pressure	The N ₂ circuit pressure relieves.

Module and Stack Configuration. The modules are designated A, B, and C going rearward from the performance panel. The module housings, valves, 1-g liquid traps, external fluid lines, and electrical connectors are shown in Figures 6.2-30 and -31. The housings provide a pressure-tight, inert N₂ environment for the stack that contains the H₂, O₂, electrolyte, and coolant. Fluid lines inside the modules are tygon tubing. Connections between the tygon and metal tubing (flared) are made by lockwire. The gas and liquid lines connected to the individual cells of the stack are 1/8-inch tygon. These lines are connected to tygon-stack manifolds, which are connected to the module inlet and outlet lines. The coolant manifolds are fabricated from stainless steel rather than tygon.

The stacks are made up of 16 basic cells placed in series between fiberglass end-plates held together by 8 through bolts. The stack dimensions are approximately 6.5 × 7.75 × 8.5 inches. Each cell is 0.35 × 7.5 × 8.5 inches. The cell and end-plate thicknesses make up the 6.5-inch dimension that runs in the direction of the centerline of the round module housings.

The O₂ and H₂ output-gas streams pass through identical liquid separators before leaving the module. The separators are fabricated from Carpenter 20 stainless steel and are about 4 inches in diameter and 1-1/2 inches thick. They consist of three fluid chambers fastened to the ends of the stack. The gases flow through the center chamber

that contains a condensing surface and dacron wicking material to retain the condensate under zero-g. The liquid is wicked to a porous-ceramic plate and forced through the plate into the outside chamber by the gas-to-electrolyte pressure differential. The outside chamber is connected to the water-feed line inside the module, and the acid stripped from the gases is recirculated directly back to the cell electrolyte pockets. Propylene glycol is pumped through the inside chamber for cooling of the gas chamber.

Outside the module housings the O_2 and H_2 pass through 1-g liquid traps, which act as backups to the zero-g separators. If the zero-g separators malfunction or the unit gas pressures drop below the electrolyte pressures, acid can be carried out of the module in the gas streams. The 1-g separators are thus intended to prevent acid from entering the unit and test-bed plumbing.

Cell Configuration. One basic cell consists of two Gemini-type current-carrier assemblies. Thin titanium sheets serve as current carriers, transmitting current between adjacent cells and electrodes through the ribs in the sheet. The sheets also make up one side of the gas pocket in which O_2 or H_2 is generated. On the other side of the gas pockets is the membrane that consists of sulfonated polystyrene, polymerized into the pore structure of a fluorocarbon matrix. The membrane is coated with platinum black, which serves as the electrode. The titanium sheet and membrane are bonded with epoxy to a fiberglass frame around the edge to make up the current-carrier assembly. Small metal tubes project through the frame to vent the gases out of the assembly.

A ribbed spacer made of hypalon rubber separates the two membranes of the cell and holds the electrolyte. The ribs of the spacer coincide with the ribs of the current carriers and thus provide positive electrical contact from cell to cell when the stack is compressed. The spacer supports a stainless-steel, 1/8-inch coolant tube, which serpentine across the electrolyte pocket making 6 passes. Two 1/8-inch glass tubes fit through the top and bottom edge of the spacer for the electrolyte inlet and outlet.

6.2.2.4 Atmospheric Contaminant Control

Particulate Filter. The particulate filter was purchased from Flanders Filters, Inc., Stock No. 7C23-C, which stipulates fiberglass filtering material without binder. The filter size is $12 \times 12 \times 5-7/8$ inches with a rating of 300 cfm and a pressure drop of 1.55 inch H_2O . The filtering effectiveness is 99.97 percent for particles above 0.3μ .

Charcoal Filter. The charcoal filter used in this system was Barnebey Cheney Model No. 7PB rated at 100 cfm with 0.3-inch H_2O pressure drop. Dimensions are $18 \times 18 \times 1-1/8$ inches, and the filter contained 7.0 pounds of activated coconut-shell charcoal having a 50-minute activity by U.S. Government accelerated chloropicrin test. The filter is a flat, perforated cell made with stainless-steel panels and frame assembly.

The prefilter employed ahead of the charcoal filter was Owens-Corning C&I Type B especially made with dimensions of 18 x 18 x 1.0 inches. The filter medium is fiberglass.

Catalytic Burner. The catalytic burner is packaged as one assembly with the exception of the differential-pressure switch, which is mounted separately. The subassemblies comprising the catalytic burner assembly are:

- a. Heat exchanger.
- b. Catalyst bed.
- c. Electric heater.
- d. Thermal switches.
- e. Frame and control panel with instrumentation and controls.
- f. Insulation caps.

Figure 6.2-33 shows the catalytic burner and a breakdown of major components.

The heat exchanger is mounted on the frame by two steel support straps. The straps open at the rear of the assembly and hinge at the front to permit removal of the heat exchanger. Each hemispherical insulation cap is held in place by three cam latches. The components under the insulation caps may be removed singly with the exception of the heater, which is mounted on the plate that retains the catalyst-bed assembly.

The control panel is fastened to the frame with a hinge at the bottom and with a cam-type fastener at each upper corner. When the fasteners are open, the panel may be swung down for access to the displays and controls mounted on the panel.

The external electrical connections and the connections between the components in the reactor housing and those on the control panel are made at terminal strips located underneath the insulation caps at each end of the frame.

The system gas-inlet-and-outlet connections are male 3/4-inch AN-37-degree flare fittings.

Heat Exchanger. This subassembly consists of the heat exchanger core, the heater mounting plate, and the mounting bases for the thermal switches.

The brazed heat exchanger core includes the reactor housing and the sheets and tubes that form the heat exchanger. The continuous dual-spiral heat exchanger configuration provides one continuous flow length for each heat-transfer circuit. With the

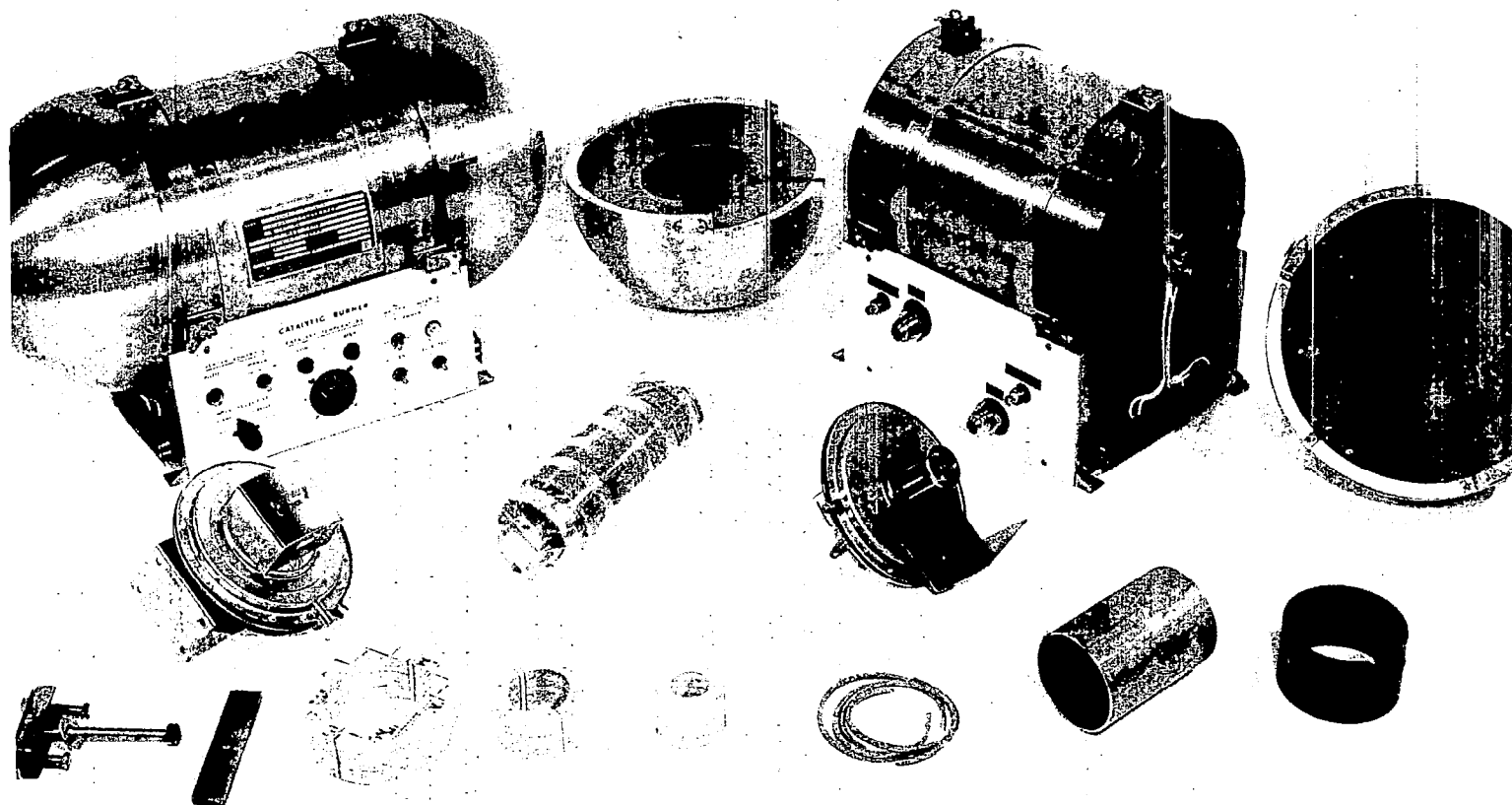


Figure 6.2-33. Catalytic Burner Assembly

hot-end manifolds used as the reactor housing, the heat exchanger core also serves as a radial insulator for the catalyst bed and heater. The reactor housing is manufactured from A1 S1 304 sheet and tubing with detail parts heliarc welded.

The heat exchanger core is assembled around the reactor housing by heliarc welding one end of each heat-transfer sheet to its respective flow stop and then wrapping the sheets and tubular closures to form a spiral. This assembly is then furnace brazed in a dry-hydrogen (-80°F dew point or less) atmosphere. Copper was used as the filler material to form the braze joints. Minor leakage points existing after brazing were filled with Englehard 301 silver brazing alloy. The fabrication of the heat exchanger was completed by assembling the cold-end manifolds, the heater mounting plate, the mounting bosses for the thermal switches, and the mounting lugs and accessory brack-etry.

The heat exchanger was designed for a maximum pressure differential across the inlet and outlet sides of 20 inches H_2O gage.

Catalyst-Bed Assembly. The catalyst-bed assembly is constructed as a cartridge. The assembly consists of the catalyst housing, the inlet tube (which encloses the system heater), inlet and outlet screens, a spacer, gaskets, micronic sintered-metal filter, retaining rings, and screws. The catalyst bed is divided into two compartments with the oxidation catalyst material occupying approximately 90 cu.in. and lithium carbonate occupying approximately 10 cu.in. Three catalyst-bed cartridges were supplied with three oxidation catalysts.

- a. MRD GAT-A-LYST on 1/4-inch alumina cylinders.
- b. 0.5 percent Palladium on 1/4-inch alumina cylinders.
- c. Copper oxide-manganese oxide, 12-20 mesh.

The cartridge is assembled by filling the catalyst-housing compartment with catalyst material, which is retained at one end by a single perforated-sheet screen and at the other end by another perforated screen and the inlet tube with its gasket. The lithium-carbonate compartment is filled with 3/8-inch cylindrical LiCO_3 pellets, which are retained by the single perforated plate at one end and the sintered filter and snap ring on the other end. The filter, made of sintered A1 S1 316 stainless steel, has a mean pore size of 35 microns and filters 98 percent of particles 8 microns and larger. Both the catalyst and the LiCO_3 may be removed separately from the cartridge. The filter may also be removed from the cartridge for cleaning or replacement.

Electric Heater. A cartridge-type electric heater is mounted in the reactor housing at the termination of the heat exchanger inlet circuit. This heater contains two identical heating elements connected in parallel so that either one or both elements can be operated. Each heating element provides the heat required to maintain the catalyst-bed discharge temperature at 700°F to 800°F with a gas-inlet temperature of 70°F .

Thermal Switches. The heater-control thermostat, located in the end of the reactor housing and downstream of the catalyst bed, operates to activate or deactivate the heater as required to maintain a preset temperature. The switch is actuated by relative movement resulting from differential expansion of a rod and tube made of different materials. The switching contacts are arranged to open on rising temperature set at a screw adjustment on the switch. Heater power is transferred through a solid-state switching device that receives its switching signal from the thermostat. Two alarm switches are incorporated to indicate low and high reactor temperature. The low-temperature alarm switch closes on decreasing temperature. The high-temperature switch closes on increasing temperature. The three switches are identical except for the opening or closing of the switch with respect to temperature. The low-temperature switch is set at approximately 700°F, the high-temperature switch at approximately 840°F, and the thermostat-control switch at a nominal 750°F. The switches and alarm lights operate from a 28-vdc power source.

Instrumentation and Controls. Figure 6.2-34 shows the catalytic burner. A differential-pressure switch (remotely mounted) is incorporated in electrical series with the heater. The switch opens to prevent heater burnout when gas flow falls below a minimum value.

A manual control override switch bypasses both the heater-control thermostat and differential-pressure switch if manual operation of the heater is desired.

Operating lights display high-temperature alarm (red), low-temperature alarm (blue), heater operation (amber), and main power (white). A bulb-test toggle checks the bulbs and indicates 115-vac power to the panel. The white power light indicates only when the bulb-test toggle is pressed. The other lights light when 28-vdc is applied to the unit and switches are closed.

NOTE: If the mode-selector switch is in the NORMAL, STANDBY, or HIGH position, depressing the bulb-test toggle, in addition to lighting the panel lights, bypasses the differential pressure and heater thermostat and directly energizes the heater elements. The mode-selector switch should thus be OFF when the bulb-test toggle is pressed. A master power switch, i.e., the mode-selector switch, controls ac power to the panel. The mode-selector switch is a four-position, three-pole, rotary switch marked for OFF, NORMAL, STANDBY, and HIGH. When the mode-selector switch is OFF, the heater is deenergized. At NORMAL, one heater element is energized. At STANDBY, the previous heater element energized at NORMAL is deenergized and the second element is energized. At HIGH, both heater elements are energized.

A thermocouple-operated pyrometer is mounted on the panel. The normal temperature input is from a chromel-alumel thermocouple in a 1/8-inch-diameter tube mounted with a 1/8-inch NPT connection in the reactor housing (along with all the thermostat switches) monitoring the temperature downstream of the catalyst bed. A second thermocouple input from a thermocouple between the heater and inlet to the catalyst bed

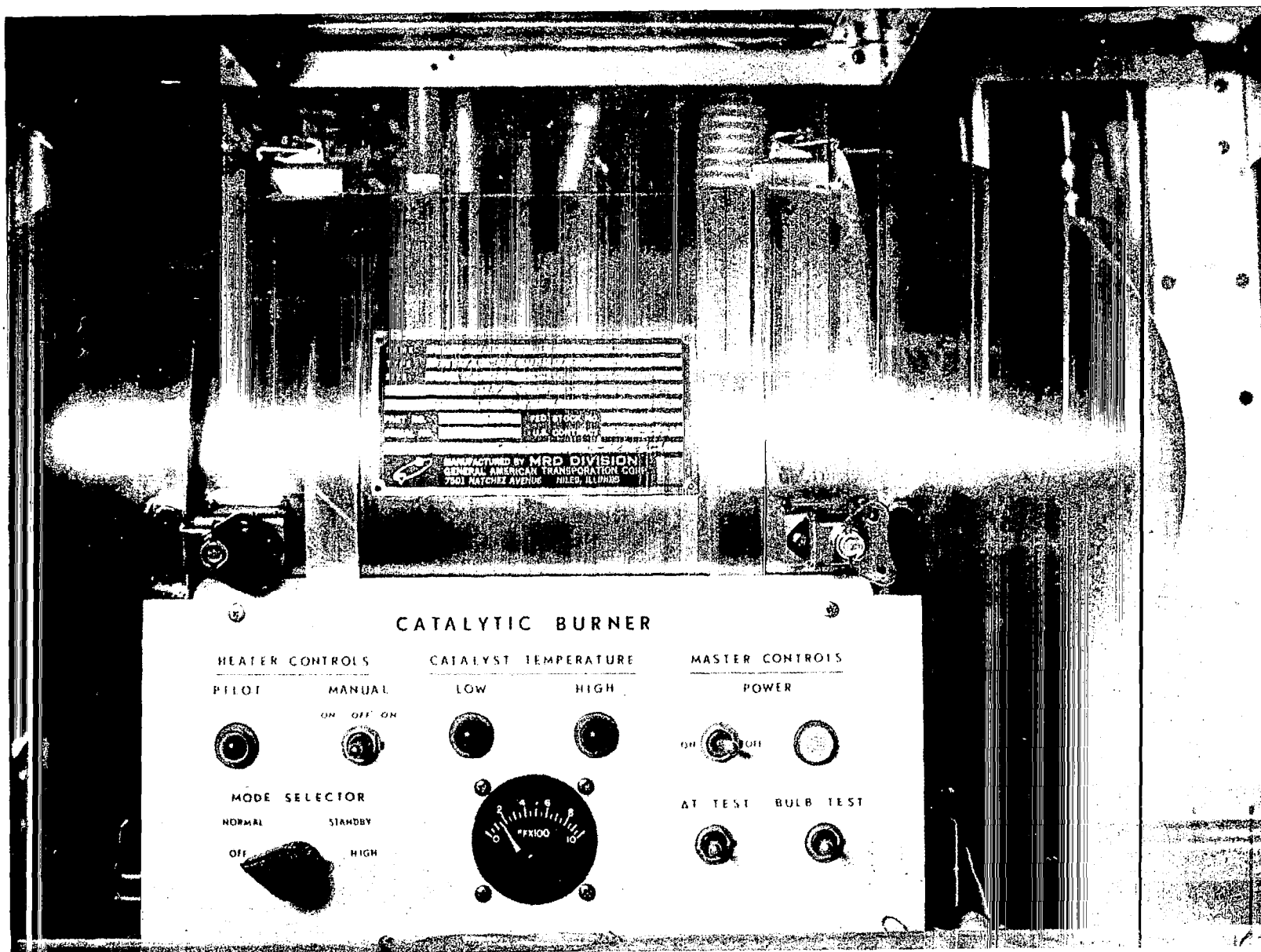


Figure 6.2-34. Catalytic Burner

may be switched into the pyrometer by depressing a ΔT test switch mounted on the panel. This thermocouple is located in a 1/8-inch-diameter well in the removable end plate at the heater end of the reactor. A second and deeper 1/8-inch-diameter well, for use with an additional thermocouple, penetrates approximately to the radial and axial center of the catalyst bed.

Additional instrumentation taps, 1/8-inch NPT female, for either pressure, temperature, or flow are adjacent to the inlet- and outlet-gas connections and also on each end plate of the catalyst housing.

Insulation Caps. Each hemispherical insulation cap is constructed from a stainless-steel spinning. The spinning retains the end-plate insulation, which is Johns-Manville Min-K 1301. The insulation was molded in place within the skin and shaped to fit the heat exchanger end plates and controls. The unit should not be lifted by the insulation caps as this can damage the insulation material.

Installation. Operational-mode and air-flow controls were installed on a separate control panel, and a flow schematic was also incorporated on this panel to identify the control and function. Figure 6.2-35 shows this panel and display.

6.2.3 WATER MANAGEMENT. The basic configuration of the prototype water-management subsystem installed in the LSS test bed is in most aspects similar to that defined by the subsystem specification. As can be determined from Figure 6.2-36 water tanks were standardized at a 46 pounds capacity each for economy purposes. Initial tests indicated that Bosch reactor product water needed processing. Thus reactor water is directed to the humidity-condensate collection circuit, and the electrolysis accumulator is fed entirely from the potable-water storage circuit.

Figure 6.2-37 is a schematic of the air evaporation unit installation. The installed units were accepted at a capacity slightly below that required of a flight unit to take advantage of existing component designs. Inadequacies within the water separator (Item 4) occasioned the addition of the separator-purge circuit (shown as Components 21, 26, 53, and 54) to avoid separator stall. Figure 6.2-38 is a rear view of the water-management subsystem showing the two evaporation units, the multifiltration unit, water tanks, liquid thermal circuits, pressurization controls, and the separator-purge circuit. Figure 6.2-39 is a photograph of the multifiltration unit while Figure 6.2-40 is a schematic of its installation.

The air evaporation unit comprises three major circuits: the waste-water circuit, the air circuit, and the product-water circuit. Principal components of these circuits are listed in the following paragraphs. Component numbers correspond to the callouts in Figure 6.2-37.

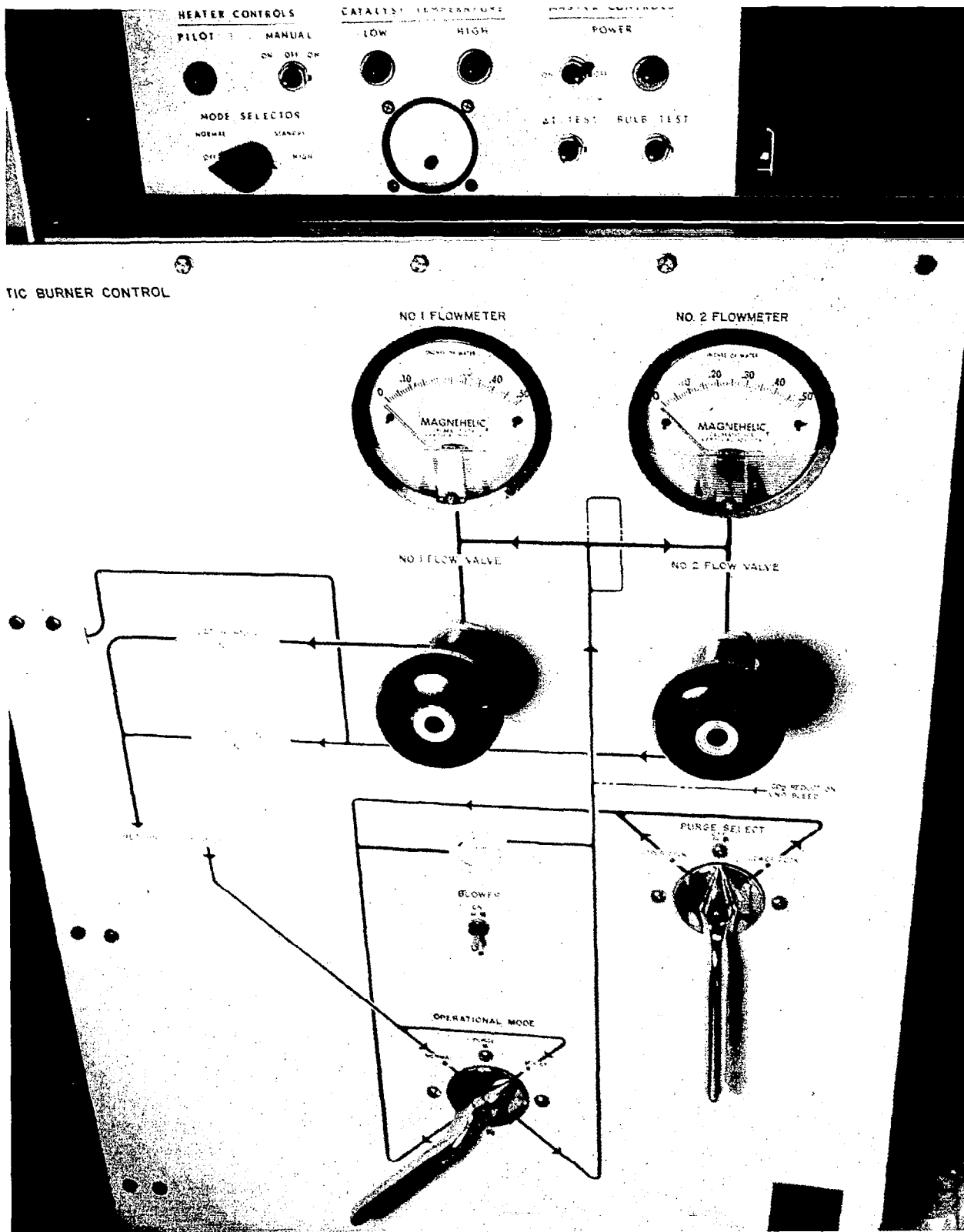


Figure 6.2-35. Catalytic Burner Control Panel

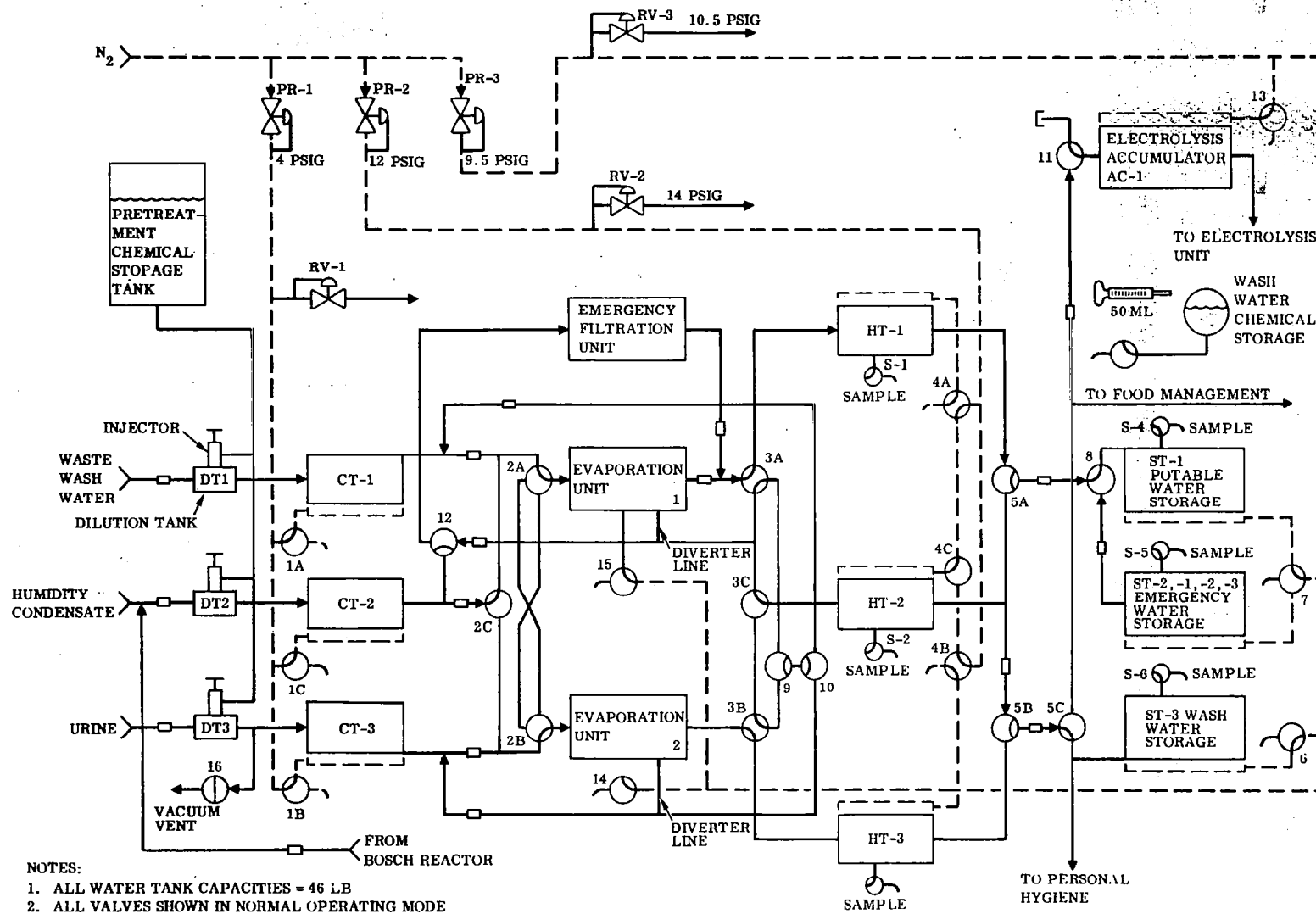


Figure 6.2-36. Water Management System Normal Mode Schematic

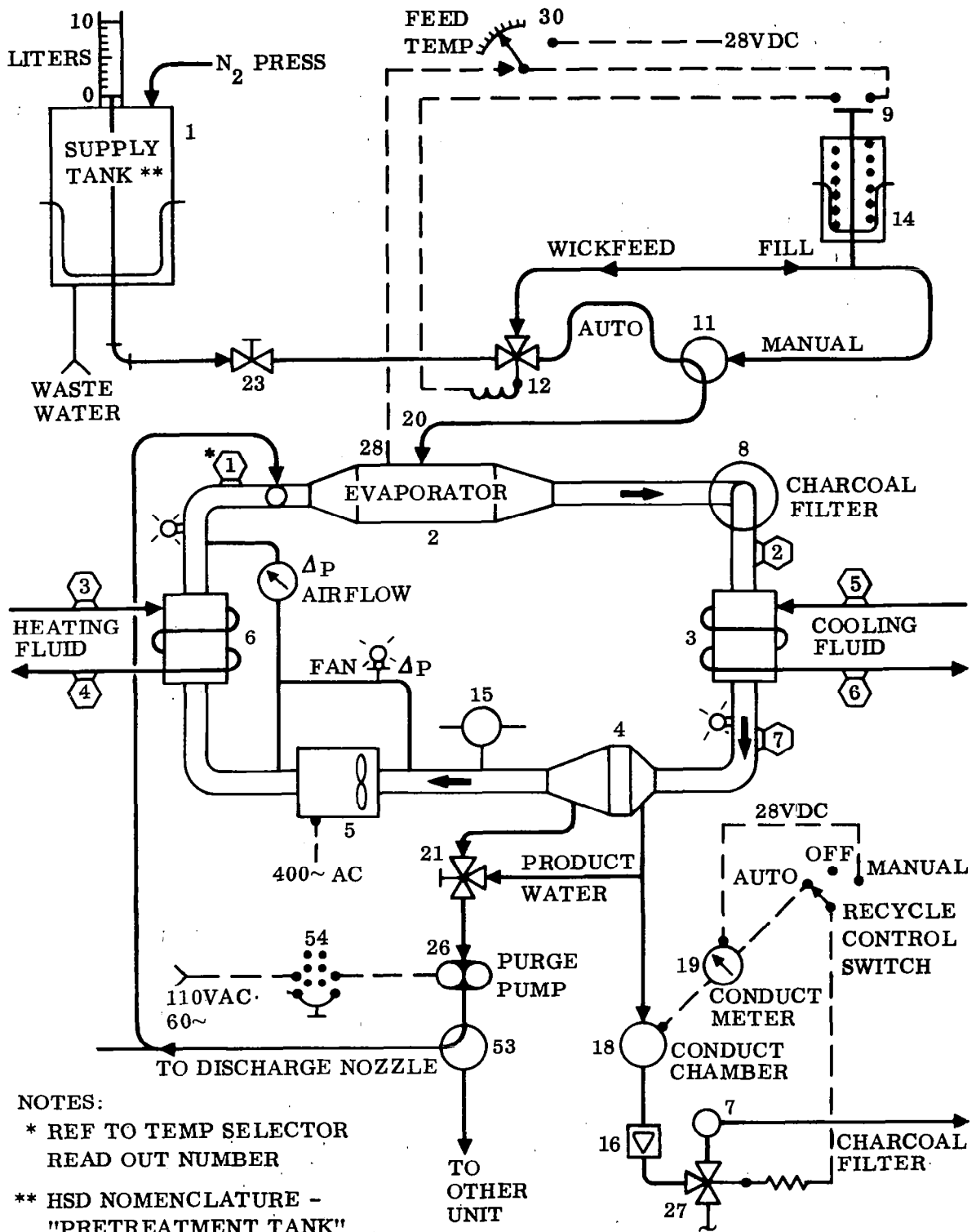


Figure 6.2-37. Evaporation Unit Schematic

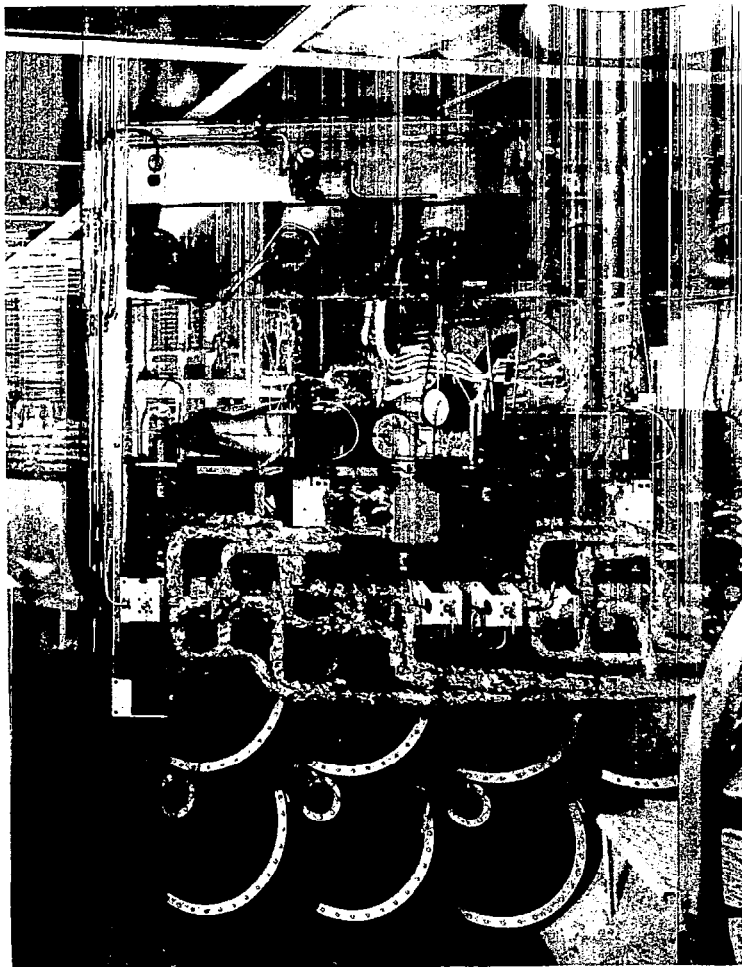


Figure 6.2-38. Back View of Water Management Subsystem

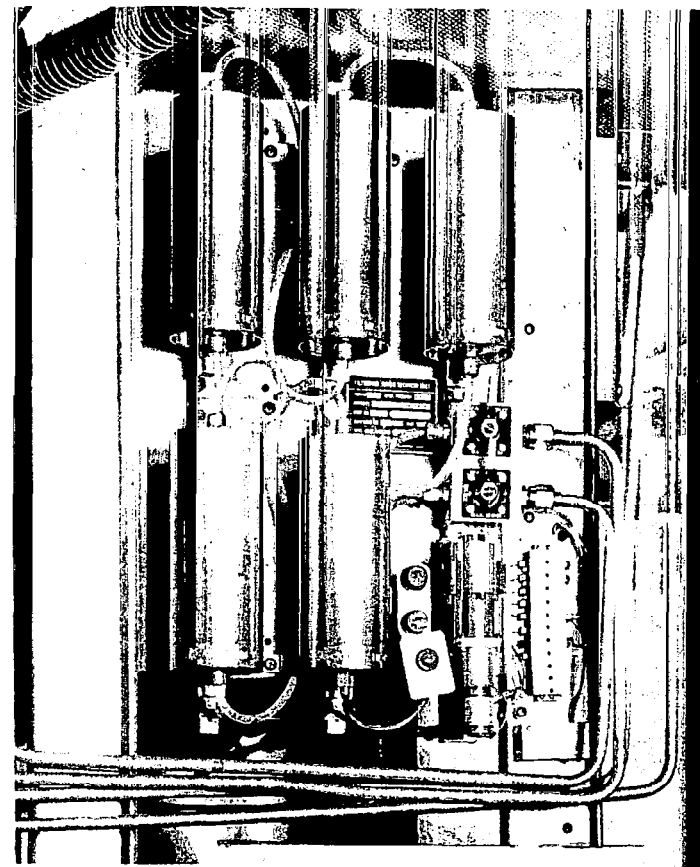


Figure 6.2-39. Multifilter Unit

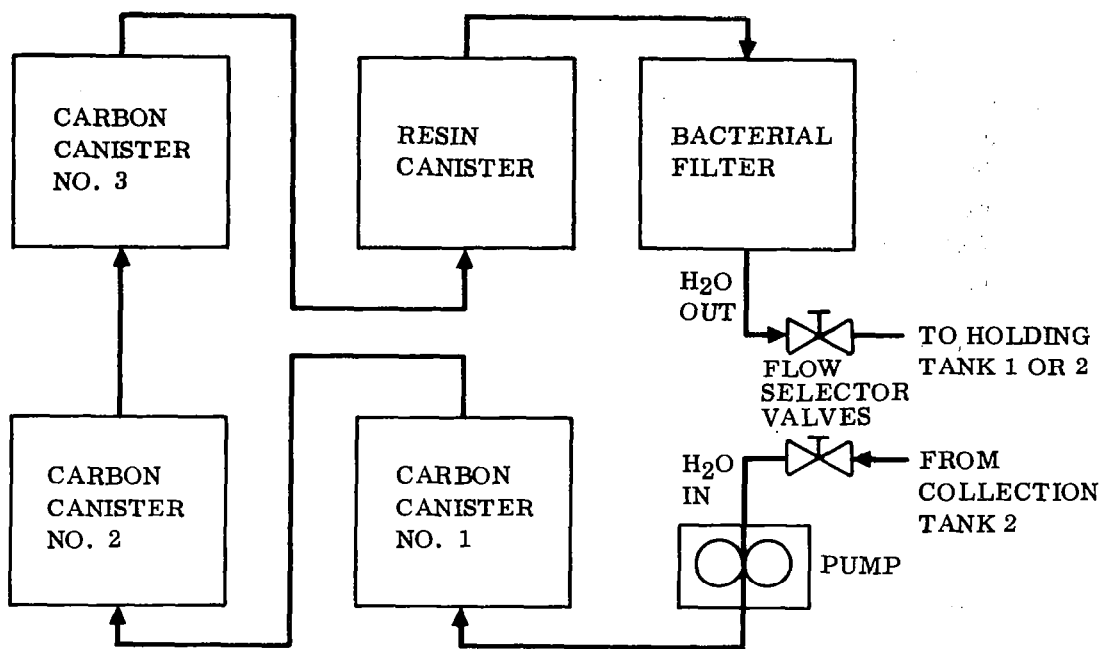


Figure 6.2-40. Multifilter Unit Schematic

6.2.3.1 Waste-Water Circuit

- a. Supply Tank No. 1 is constructed of corrosion-resistant AlSi1316 with a waste-water (pretreated urine) capacity of approximately 10 liters. Provisions are made for positive expulsion and confinement under zero-g by a gas-pressurized, fabricated-silicone, rubber-roll diaphragm. A diaphragm follower extending into a sealed cylinder with transparent window acts as a water-level gage.
- b. Evaporator Feed Control is composed of
 1. Batch Feed Tank No. 14, a stainless-steel tank with a spring-loaded, silicone roll diaphragm set for a capacity of approximately 600 cc.
 2. Batch Feed Solenoid Valve No. 12, a valve that in normal (electrical OFF) position feeds waste water to the batch tank and maintains the batch tank fully charged. On electrical signal, the valve closes the supply line and opens the spring-loaded charge of the batch tank to the Evaporator Wick Feed Valve No. 20, which in turn transports the waste water to the wick distribution manifold.
 3. Wick Temperature Sensor No. 28, a thermistor embedded in the leading edge of the wick. The temperature being sensed is a combination of the process-air stream (approximately 160-170°F) and the cooling effect of evaporation. As the wick dries, the sensed temperature increases.
 4. Wick Temperature Meter Relay No. 30, a commercial meter relay with adjustable relay set point, receives the temperature signal and closes 28-vdc circuit to actuate the control valve when the set-point temperature is reached.

6.2.3.2 Air Circuit. The air circuit, essentially closed, carries the primary process stream and comprises both dynamic and static components constructed primarily from anodized aluminum alloys in a near flight configuration.

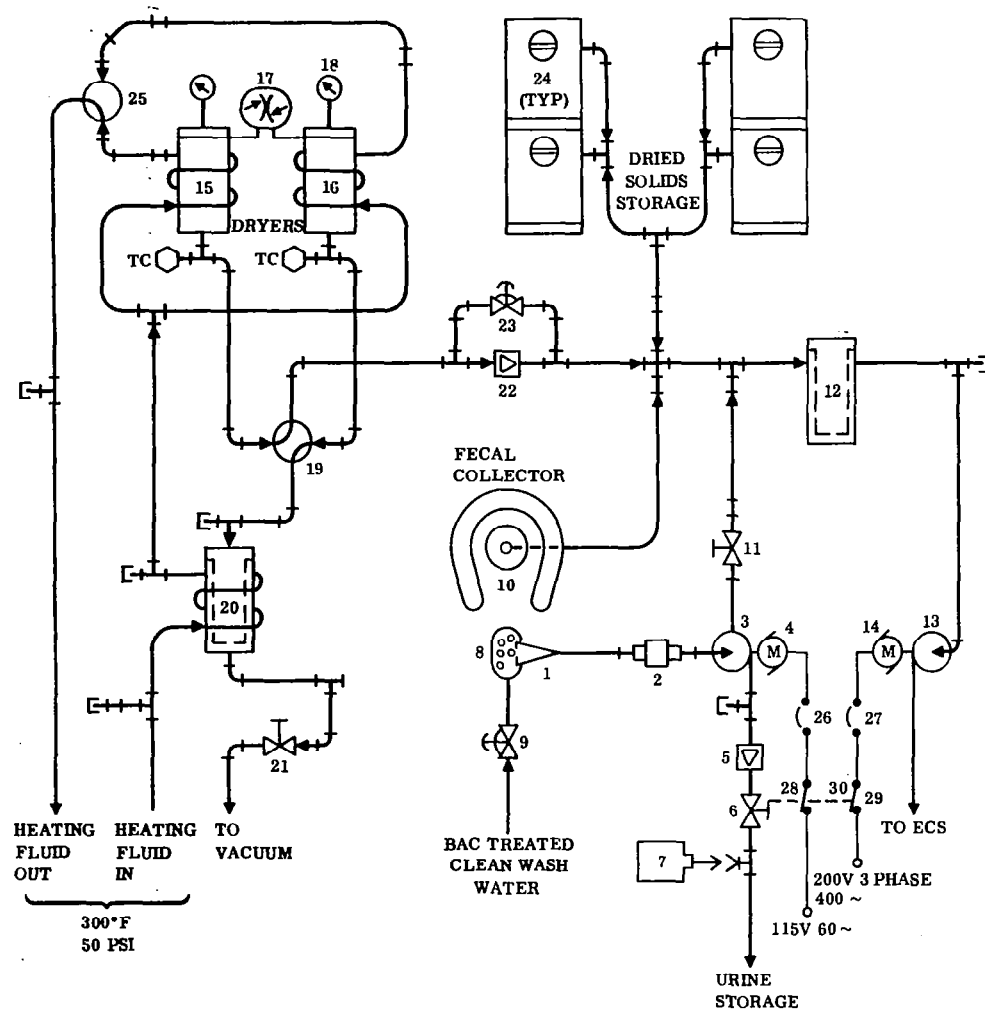
- a. Evaporator (2). The evaporator cover houses the evaporator core (wick). The cover is hinged to permit easy access and removal of the wick. The evaporator core is a rayon-felt wick, approximately 4 × 16 × 8 inches, through which 33 slotted channels provide process-air passage. The core is encased in plastic materials with transparent inlet and outlet headers for air-stream ducting from the fixed air circuit ducts. A waste-water distribution manifold with a feed-valve fitting is an integral part of the wick.
- b. Charcoal Filter No. 8 comprises a housing and removable filter cartridge. The filter takes the full flow of the evaporator outlet process stream and operates to reduce odor carryover from the evaporator.
- c. Heat Exchangers (Condenser No. 3 and Heater No. 6). The heat exchangers were fabricated from existing flight hardware. The condenser, installed downstream of the charcoal filter, employs coolant from the system thermal-control circuit and operates to reduce process-air stream temperatures from a range of 40 to 70° F. The heater, installed upstream of the evaporator employs process-heating fluid to raise air-stream temperatures from the condensing temperature range to the evaporating temperature range of 150 to 175° F.
- d. Water Separator No. 4, an adaptation of an existing flight article, is a turbine (process-air stream impingement) driven centrifugal unit located immediately downstream of the evaporator. The unit collects the entrained water and pumps it to the product-water circuit and then to the selected water-management holding tank.
- e. Recirculating Fan No. 5, a motor-driven (400 cps) axial fan located immediately downstream of the water separator, provides continuous recirculation of the process-air stream.
- f. Air-Circuit Relief Valve No. 13 is a double-element valve that operates to both over- and under-pressure to maintain essentially cabin ambient pressures within the process-air circuit while minimizing the actual air exchange.
- g. Instrumentation
 1. Temperature readouts
 - a) Evaporator inlet and outlet
 - b) Condenser outlet plus coolant in and out
 - c) Heater process heat in and out
 - d) Wick temperature
 2. Air Flow, AP
 3. Warning Lights
 - a) Fan AP

- b) Evaporator IN
- c) Condenser OUT

6.2.3.3 Product-Water Circuit

- a. Conductivity Sensor No. 18 is a probe-type sensor installed immediately downstream of the water separator product-water outlet and operates in conjunction with the conductivity meter relay to measure water conductivity.
- b. Back-Pressure Valve No. 16 is an adjustable spring loaded variable orifice located downstream of the conductivity sensor chamber to provide an appropriate back pressure on the water separator to maintain a sufficient "level" of water in the separator to assure adequate separation effectiveness.
- c. Recycle Solenoid Valve No. 27 normally permits passage of product water through the valve and into the water-management holding tanks. When electrically activated it recycles product water to the waste-water collection tank. The valve is activated either by the automatic conductivity sensing circuit or manually.
- d. Charcoal Filter No. 7 is installed in the normal product-water line downstream of the recycle valve and operates as a backup or secondary filter to minimize odors and accompanying trace tastes that might accompany the product water during periods of air stream charcoal filter "load-in".
- e. Conductivity Meter Relay receives a signal from the sensor circuit and closes the recycle valve 28-vdc circuit when the conductivity set point has been reached.
- f. Water Separator Purge Circuit is a secondary product-water circuit (consisting of manual selector valves, water pump, and discharge nozzle) that drains water from the separator case and water-output circuit to reduce rotational drag on the separator. Purge is often required at startup but seldom if ever during normal system operation. Purged water is returned to the process-air stream at the inlet to the evaporator.

6.2.4 WASTE MANAGEMENT. The installed prototype waste-management subsystem (Figures 6.2-41 and 6.2-42) is essentially that defined by the subsystem specification. Simplification of the process-heat circuit, which eliminated the DC-331 bypass and throttling valve, was possible. Metal baskets were added for each dryer to provide for extra protection against collector-bag deterioration and handling damage and to reduce the need for dryer bags to supplement the collection bags. Urinal flushing with clean wash water (BAC treated) from the personal hygiene subsystem was substituted for the originally defined disinfectant circuit. In addition to the savings from integration with the existing personal hygiene circuit, problems that might have been associated with water recovery from the disinfectant were avoided. Changes were made in the design of the liquid/gas separator to decrease vibration, increase available torque, improve both separation effectiveness and pumping characteristics, and decrease corrosion. These changes included replacement of the torque-limited drive



LEGEND		
ITEM	QUANTITY	
1	1	URINAL
2	1	URINE FILTER
3	1	SEPARATOR ASSY
4	1	MOTOR B2224
5	1	CHECK VALVE
6	1	URINE FLUSH VALVE
7	1	EMERGENCY URINAL
8	1	URINAL BRACKET
9	1	RINSE VALVE (MOMENTARY)
10	1	FECAL CAN ASSY
11	1	FLOW CONTROL VALVE
12	1	ODOR FILTER ASSY
13	1	BLOWER
14	1	MOTOR 400 ~ AC
15	1	DRYER ASSY (RT)
16	1	DRYER ASSY (LT)
17	2	VACUUM GAGE
18	2	TEMP INDICATOR DRYER
19	1	VACUUM SELECTOR VALVE
20	1	VACUUM FILTER ASSY
21	1	SHUTOFF VALVE
22	1	CHECK VALVE
23	1	VACUUM RELEASE VALVE
24	4	WASTE STORAGE CONTAINER ASSY
25	1	HEAT SELECTOR VALVE
26	1	CIRCUIT BREAKER
27	1	CIRCUIT BREAKER
28	1	URINAL FLUSH VALVE MICRO SWITCH
29	1	URINE FLUSH VALVE SWITCH
30	1	SWITCH EXT LEAF
-	AR *	REPLACEMENT CARTRIDGE

* AS REQUIRED

Figure 6.2-41. Waste Management System Schematic

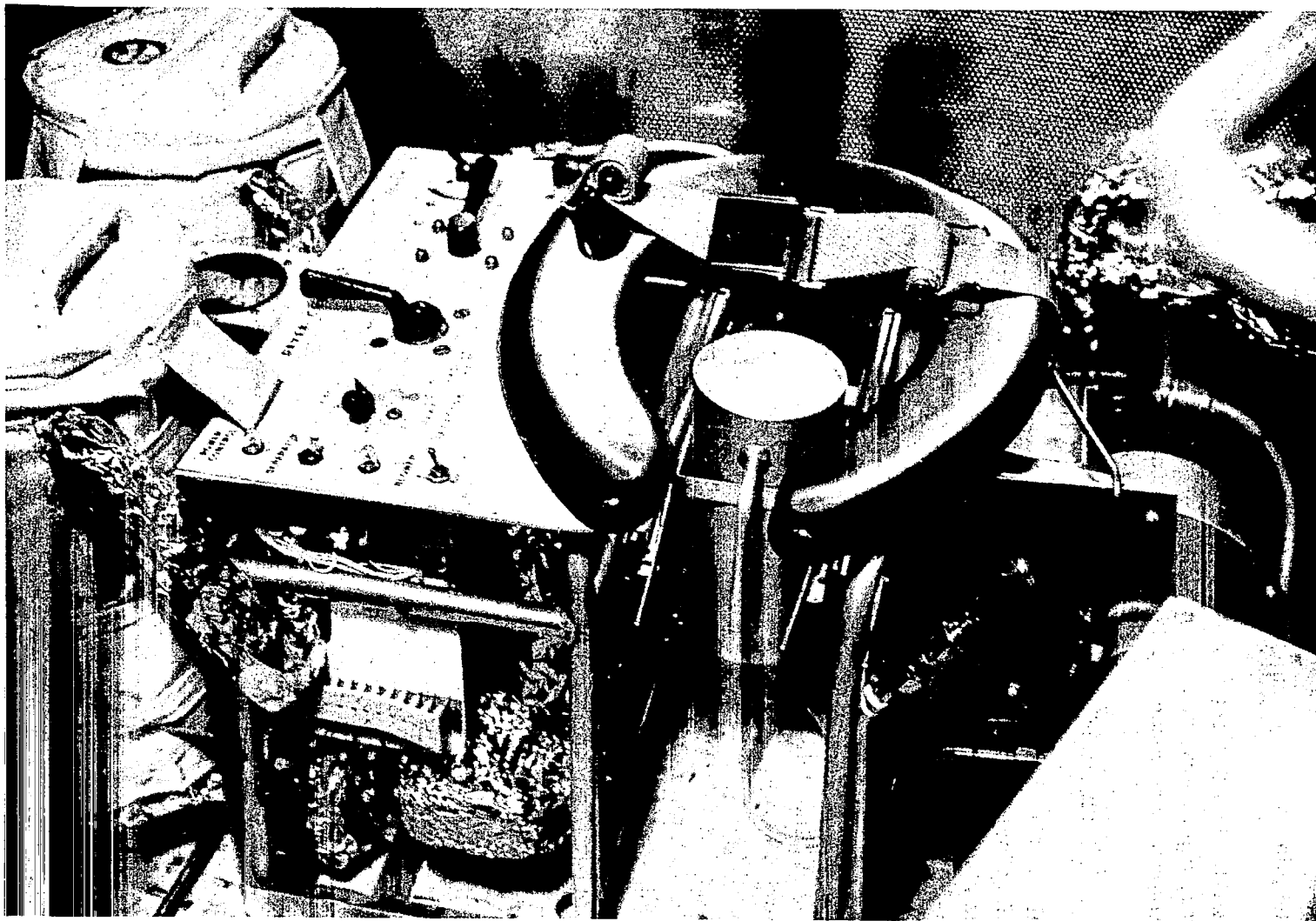


Figure 6.2-42. Waste Management Assembly

motor (400 cps) with a 60-cps motor, installation of an additional support bearing, rework of the pilot-water pickup, and change of materials.

The waste-management subsystem comprises a collection circuit, a dryer circuit, four storage containers, and a supply cabinet. Components are described in the following paragraphs. Component numbers correspond to the callouts in Figure 6.2-41.

6.2.4.1 Collection Circuit

- a. Fecal Can No. 10, a container located below a conventional toilet seat, is adjustable fore and aft for individual differences. An expendable semipemreable paper bag is placed in the can as a liner and as a container for removal of the feces. Zero-g operation is attained by air flow from the cabin drain through the bag and fecal can by an attached flex tube, which in turn is connected to the inlet of a charcoal filter and the installed blower.
- b. Air Stream Blower No. 13, a high-speed miniature centrifugal blower (approximately 5 scfm) driven by a 400-cps motor, is mounted in the air-stream circuit to provide zero-g operation of the feces and urine collector and to provide boost capability to the feces dryer and waste-storage containers. The blower outlet dumps to the inlet of the main system cabin blower and thence across the charcoal filters back to the cabin atmosphere.
- c. Urinal No. 1 is a cone-shaped collector attached to the installed liquid/gas separator by a plastic flex tube through which the collection air stream is drawn. The collector is stored at a wall-mounted attachment Bracket No. 8. Urinal Flush Circuit No. 9 discharges clean treated wash water through swirl discharge nozzles at the mounting bracket.
- d. Liquid/Gas Separator No. 3, a motor-driven centrifugal separator whose case is vented to the air-stream blower, draws urine into the separator and then pumps the air-free urine to the water management subsystem for recovery processing. Electrical Switches No. 28, 29, and 30, for the separator and air-stream blower, are ganged and in turn are ganged to the urinal flush Valve No. 6 to assure proper management.
- e. Air Stream Bacterial and Odor Filter No. 12 is installed at the inlet to the air-stream blower to minimize odors and bacterial transfer to the system ECS. The filter is a double-element charcoal and particulate filter.

6.2.4.2 Dryer Circuit. Feces and other waste drying is accomplished by two thermally supported vacuum dryers. One dryer operates alternately in a drying mode while the other acts as the collecting dryer. Instrumentation, filtration, vacuum and thermal circuits, and controls are included.

- a. Dryer No. 15. Each dryer (approximately 230 cu.in. internal volume) is provided with a sealed, hinged lid, and temperature and pressure installation. Valves No. 19, 23, and 21 place the dryer chamber in the vacuum drying mode or the air-stream blower vented mode. Process heat is introduced to the dryer surface coils to support vacuum drying; selection is accomplished by Valve No. 25.
- b. Space Vacuum Bacterial Filter No. 20, an 0.15-micron filter, is located in the vacuum vent circuit to minimize "space" contamination. Sterilization of the filter is accomplished by filter-case surface heating from the process-heat circuit upstream of the dryer heaters.

6.2.4.3 Storage Containers No. 24. Four cylindrical containers (approximately 5 ft³ each) each with a sealed access door are provided with air-stream vents. Each container includes overcenter clamp holddowns to provide vents to the floor and to permit stacking.

6.2.4.4 Supply Cabinet is a storage cabinet to provide easy access to expendables such as collection bags, drying bags, storage bags, and toilet paper. A 100-day supply of expendables was included.

6.2.5 PERSONAL HYGIENE. The personal-hygiene subsystem in the prototype system employs sponge bathing for body cleansing supplemented with chemical dry wipes for special or superficial cleansing, and a commercial electric razor for grooming. The sponge wetting and rinsing circuit is comprised of a water heater that delivers 125°F water (pre-treated with BAC at the water-management storage tank) to a manually operated sponge wetter and rinser. This unit in turn discharges the used wash water from the sponge to a liquid/gas separator that in turn pumps the waste water to the water-management collection tank. A water-temperature indicator and an over-temperature cutoff light is provided at the subsystem panel. A cabinet with a polished-metal (mirror) door and self-mounted tie-down springs is included as are storage-dispensers for chemical wipes. Figure 6.2-43 shows the general arrangement, 6.2-44 is the schematic of the sponge-squeezer circuit, and 6.2-45 the schematic of the water-heater circuit. Component descriptions follow:

- a. Water Heater No. 11. The wash water heater (identical in capacity and control to food water heater) provides 125°F water to the sponge squeezer. The heater receives its water supply directly from the water-management system at approximately 10 psig. Temperature control is provided by a process-heat flow-control Valve No. 9 that is positioned as a function of water temperature. The valve actuator is a spring and mechanical extension of the temperature sensor that translates its expansion and contraction into valve position.
- b. Bypass Solenoid No. 8 is located in the water heater process-heat circuit. When operating normally (heater on), the valve is electrically on and ports fluid to the heater temperature-control circuit. When electrically off the valve bypasses the heating fluid around the heater. The valves are positioned in bypass either by

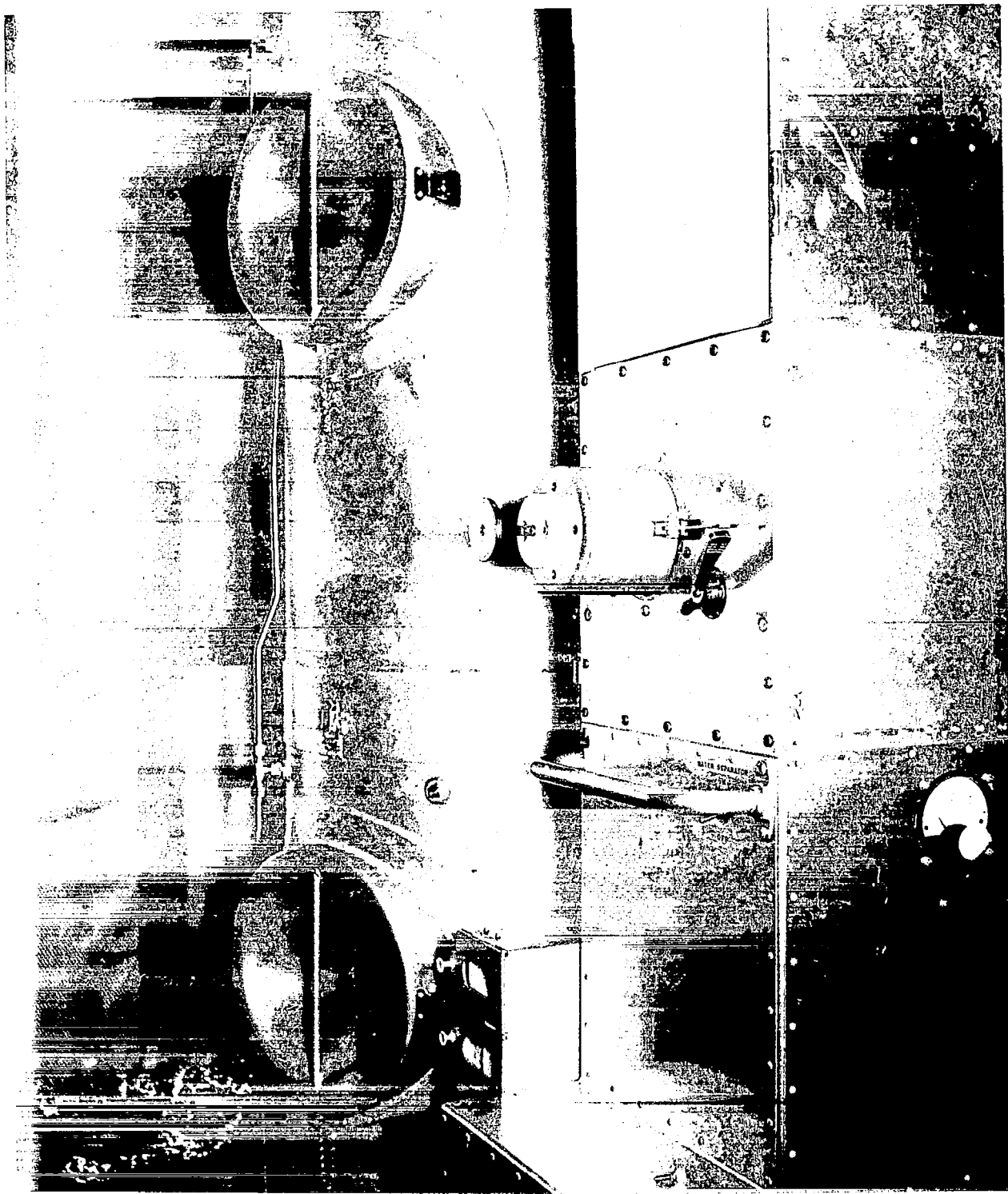


Figure 6.2-43. Personal Hygiene Panel

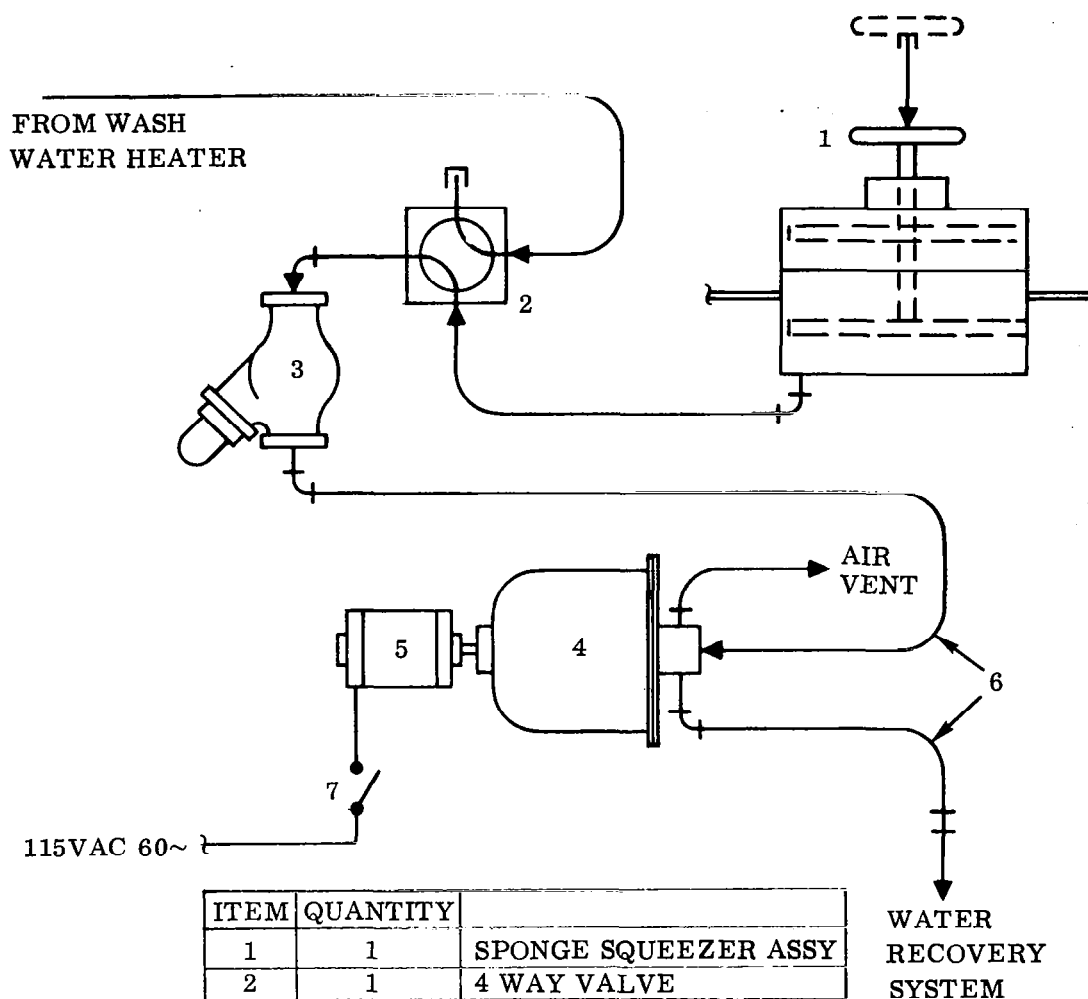


Figure 6.2-44. Sponge Squeezer Circuit

manual switches at the system status panel or by the temperature limiting Thermostat No. 14 that opens the solenoid 28-vdc circuit at 180°F. A panel-mounted light indicates that an overtemperature condition has occurred.

- c. Sponge Squeezer No. 1 is a manually operated piston-cylinder arrangement into which a sponge can be placed. Actuation of the piston draws in or expells water to the extent desired by the operator.

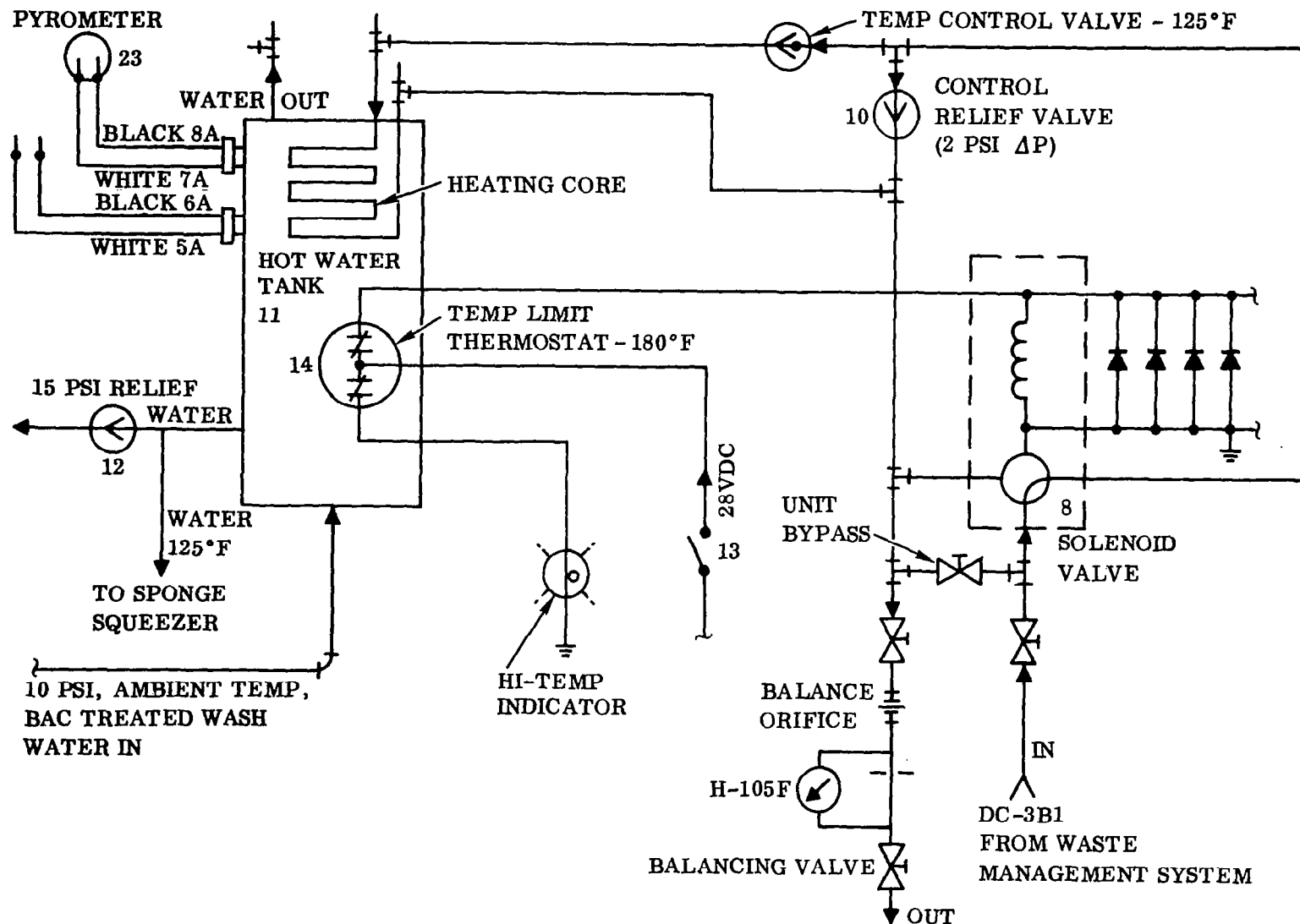


Figure 6.2-45. Hygiene Water Heating System Schematic

- d. Liquid/Gas Separator No. 4 is a motor-driven centrifugal separator (identical to the urine-collection separator) that accepts waste water, suds, and air from the sponge squeezer. Air is vented to the cabin while waste water is pumped to the water-collection system at approximately 5 psig.

6.2.6 FOOD MANAGEMENT. The prototype food-management subsystem as initially installed consisted of:

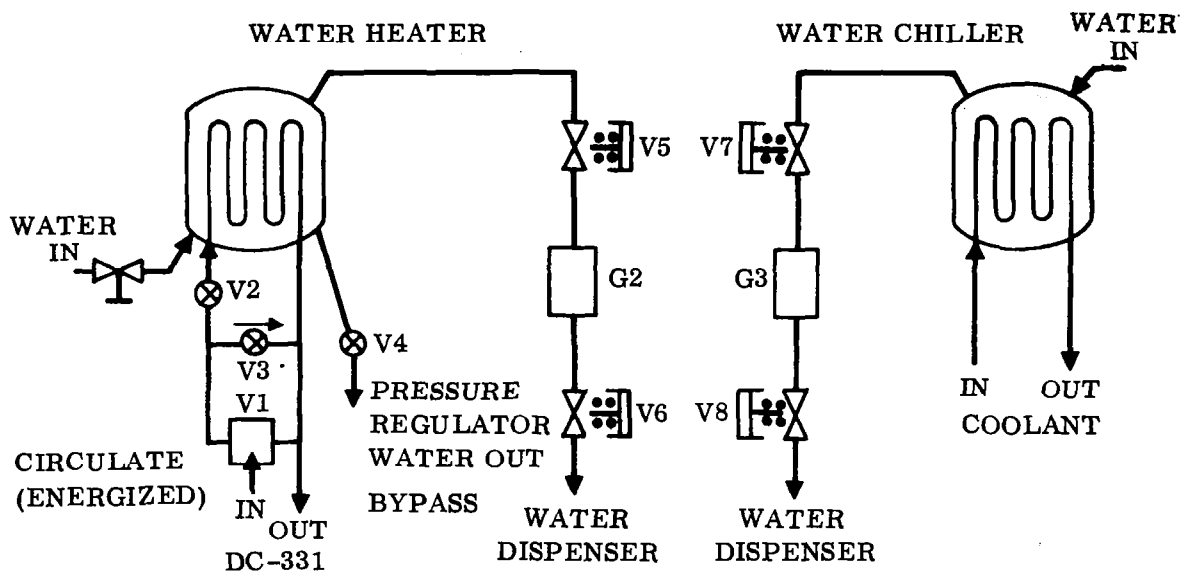
- a. Storage racks for 100 days of food for 4 men with food canisters for a 10-day food supply.
- b. Two food and beverage trays providing thermal insulation and package holddown.
- c. A water supply-and-conditioning (heating and cooling) unit with provisions for metering and dispensing specified selected quantities directly into the food containers.
- d. A 10-day supply of food for 4 men that provides 2,800 K cal/man-day of a composition and quality as specified.

Figure 6.2-46 shows a crewman reconstituting a hot beverage, Figure 6.2-47 is a simplified schematic of the water heater, water chiller, and dispensing circuits. Component descriptions follow.

- a. Water Heater is identical to wash water heater of the personal-hygiene subsystem except that the temperature controller operates at approximately 165° F. Potable water is received directly from the potable-water storage tank(s) of the water-management subsystem. Process-heating fluid is received from the output of the water-management evaporation units at approximately 200° F.
- b. Water Chiller cools water to approximately 35 to 40° F with a capacity sufficient to supply drinking water and/or cold beverage reconstitution for 2-man meals served every 2 hours. No temperature controls are required.
- c. Water Dispensers. Each conditioned-water source is provided with a dispensing circuit comprised of three major components as follows:
 - 1. Meter Chamber No. G2 is a cylinder with spring-loaded piston that can be charged to any desired level with pressurized water from the conditioning unit and can discharge its contents as permitted by the operator. A piston follower extends to a scale marked in ounces to enable the operator to select the proper charge as dictated by the requirements of the food being reconstituted.
 - 2. Meter Fill Valve No. V5 is a spring-load valve with push-to-open action that the operator actuates to charge the meter chamber to the correct level.
 - 3. Water Dispenser Nozzle No. V6 is a nozzle configured to insert into the plastic food containers and incorporates a spring-loaded push-to-open valve. The nozzle is capable of swinging through an arc of approximately 225 degrees in a plane perpendicular to the face of the console.



Figure 6.2-46. Meal Preparation



ITEM	DESCRIPTION
V ₁	THREE-WAY SOLENOID VALVE
V ₂	THERMALLY ACTUATED THROTTLE VALVE, HEATING FLUID CONTROL
V ₃	PRESSURE RELIEF VALVE, HEATING FLUID CONTROL
V ₄	PRESSURE RELIEF VALVE, WATER
V ₅ AND V ₇	POPPET VALVE (PUSH TO OPEN), METER GAGE FILL
V ₆ AND V ₈	POPPET VALVE (PUSH TO OPEN), WATER DISPENSER
G ₂ AND G ₃	WATER VOLUME METER GAGE

Figure 6.2-47. Fluid Management Fluid Circuit

6.2.7 INSTRUMENTATION AND CONTROLS. The instrumentation and control system is a composite of the subsystem equipment panels, the onboard operating status panel, and the ground control console linked together by the electrical-power control networks, the warning-light/alarm network, and the gas sampling network.

6.2.7.1 Subsystem Equipment Panels. The subsystem equipment panels provide the necessary data, e.g., significant temperatures, pressures, flows, for evaluation and maintenance. The instrumentation and controls were modified where proven inadequate

or inappropriate by test-program results or equipment redesign. (Refer to General Dynamics Convair Reports 64-26229 and 64-26232 for detail changes.) Significant changes at equipment level are as follows.

a. CO₂ Concentration Unit. The CO₂ concentration unit panel (Figure 6.2-48) was modified by adding a back-lighted schematic showing real-time valve positions and valve-sequential programmer-cycle position. Due to the cyclic nature of the CO₂ concentration unit, time on-the-line and system-flow configuration is required to evaluate system performance.

b. CO₂ Reduction Unit. The CO₂ reduction unit panel (Figure 6.2-49) underwent a deletion of instrumentation and controls due to the system redesign elimination of the blowback compressor and filter valves. The functions of the Bosch reactor auxiliary and main heaters were interchanged to increase heater life and decrease temperature gradient. A variac power control and wattmeter were added to the auxiliary heater circuit and the temperature controller was transferred from the main heater to the auxiliary heater. The auxiliary heater maintains reactor temperature by cycling between one-half line power through a power diode and the variac power setting. (Refer to General Dynamics Convair Report 64-26229 for details.)

c. Water Electrolysis Unit (Figure 6.2-50). It became evident during SAI and subsequent tests that a coolant control was required to stabilize performance and minimize potential cell failure due to overtemperature. The temperature-control requirement was defined as 90°F ± 2°F. The installed iron constantan thermocouple was by definition to be the control sensor. Control systems evaluated were

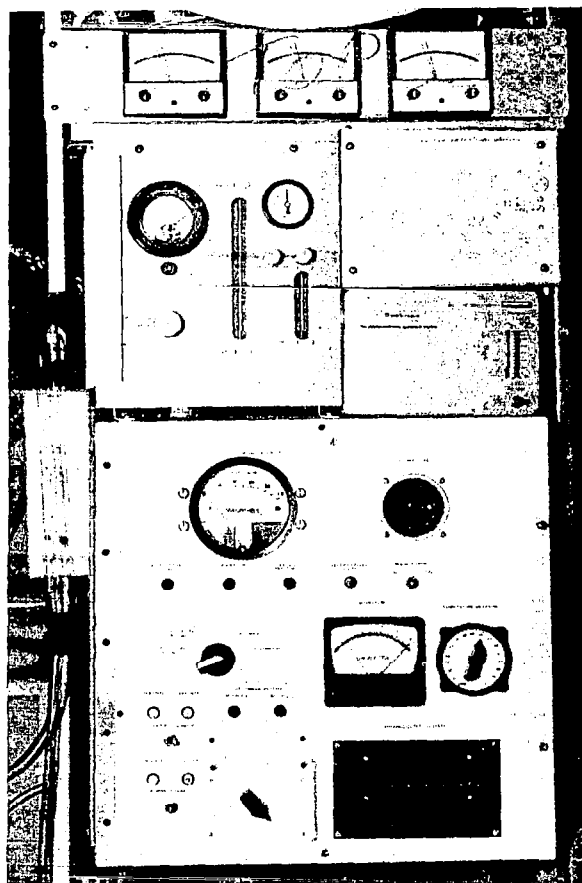


Figure 6.2-48. CO₂ Concentration Panel

Figure 6.2-49. CO₂ Reduction Panel

the commercial mag amp and pyrometer-type controllers. The taut-spring photoelectric pyrometer controller manufactured by API promised better accuracy, visual readout, and a second set point that could be used for overtemperature cutoff. Separate controllers were installed for each module; operational testing verified acceptable system performance.

Diodes were added in series with each module to prevent reversing polarity on cells, which would cause explosive H_2O_2 mixture.

Diodes were added to module off-alarm circuits to prevent applying power to the modules through these circuits even though the module power switches were off.

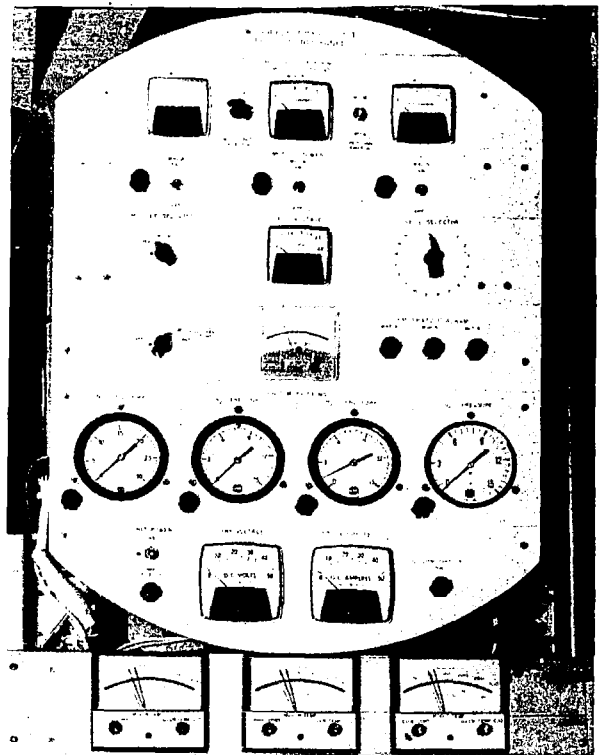


Figure 6.2-50. Water Electrolysis Panel

- d. Catalytic Burner. Two minor modifications were made to increase reliability and enhance system safety. A change in the thermostat control-system circuit eliminated the requirement for ac-heater power to pass through the control thermostat. This change was to install a solid-state switching device between thermostat and the heater.

An interlock network was added to prohibit CO_2 reduction recycle gas venting to catalytic burners unless one of the catalytic burners is operating at acceptable flow and temperature. This prohibits an accumulation of explosive concentration in the catalytic-burner circuit or expulsion of toxic recycle gasses into the cabin atmosphere.

- e. Air Evaporation Water Process Units (Figure 6.2-51). Minor modifications were made to the feed water control and conductivity circuit to remove problem areas and increase reliability. The troublesome closed-loop evaporator inlet temperature control was replaced by a simple, more reliable open-loop control. The conductivity high override and diverter valve switch were combined to a single, three position, recycle control switch.

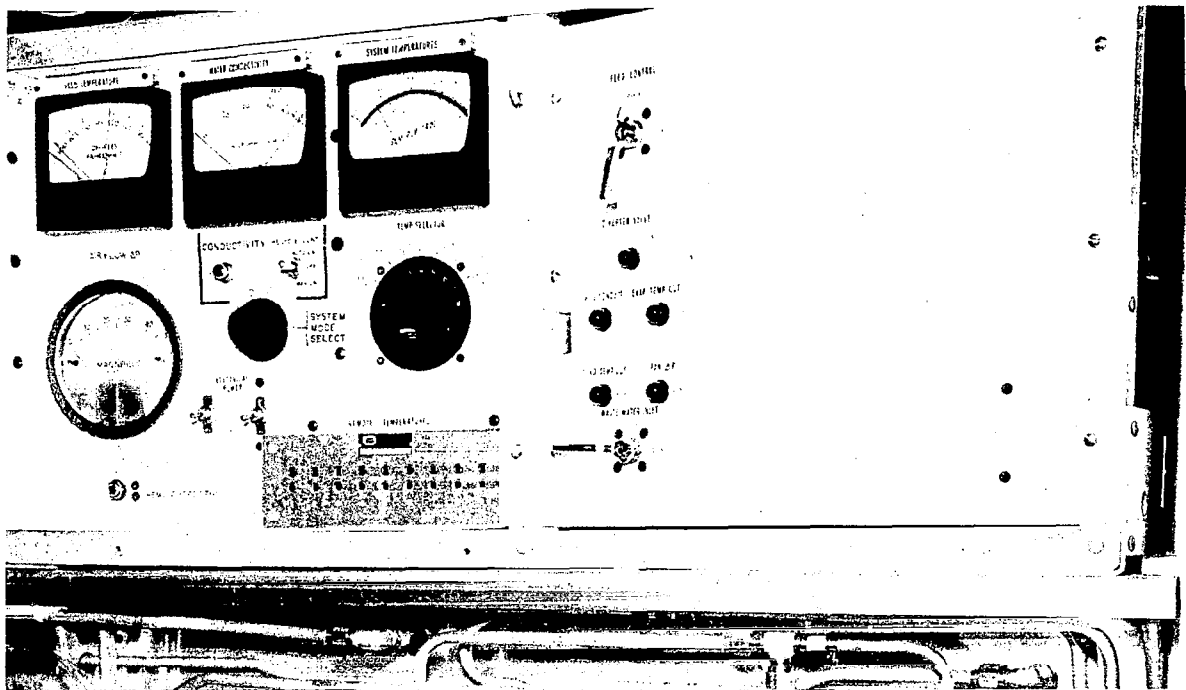


Figure 6.2-51. Air/Evaporation Process Panel

- f. Heating and Pumping Unit. The fluid circuit, temperature sensor, remote temperature selector, and bridge circuit were modified to provide continuous fluid flow through the heater and to permit full heater control over $\pm 3^{\circ}\text{F}$ thus eliminating cyclic temperature variations.

6.2.7.2 Operating Status Panel. The operating status panel (Figure 6.2-52) is centrally located and organized to permit rapid evaluation of the overall LSS system status. The display is grouped by subsystems in a functional arrangement with the most sensitive or critical system function at the top. Each subsystem display includes warning lights and power-control switches. Warning lights identify out-of-tolerance operation or unit power off or on for normally operating units or emergency-type, normally off units respectively. Electrical-power control is provided for emergency shutdown and equipment maintenance.

Normally, all lights are off with the exception of a green SYSTEM OK light. Any subsystem out-of-tolerance condition will light a warning light accompanied by an audible alarm. Concurrently the SYSTEM FAILURE light turns on and SYSTEM OK turns off. This concept provides two desirable features, rapid failure evaluation and minimum power. The crew need not visually single out a light in a Christmas tree of lights.

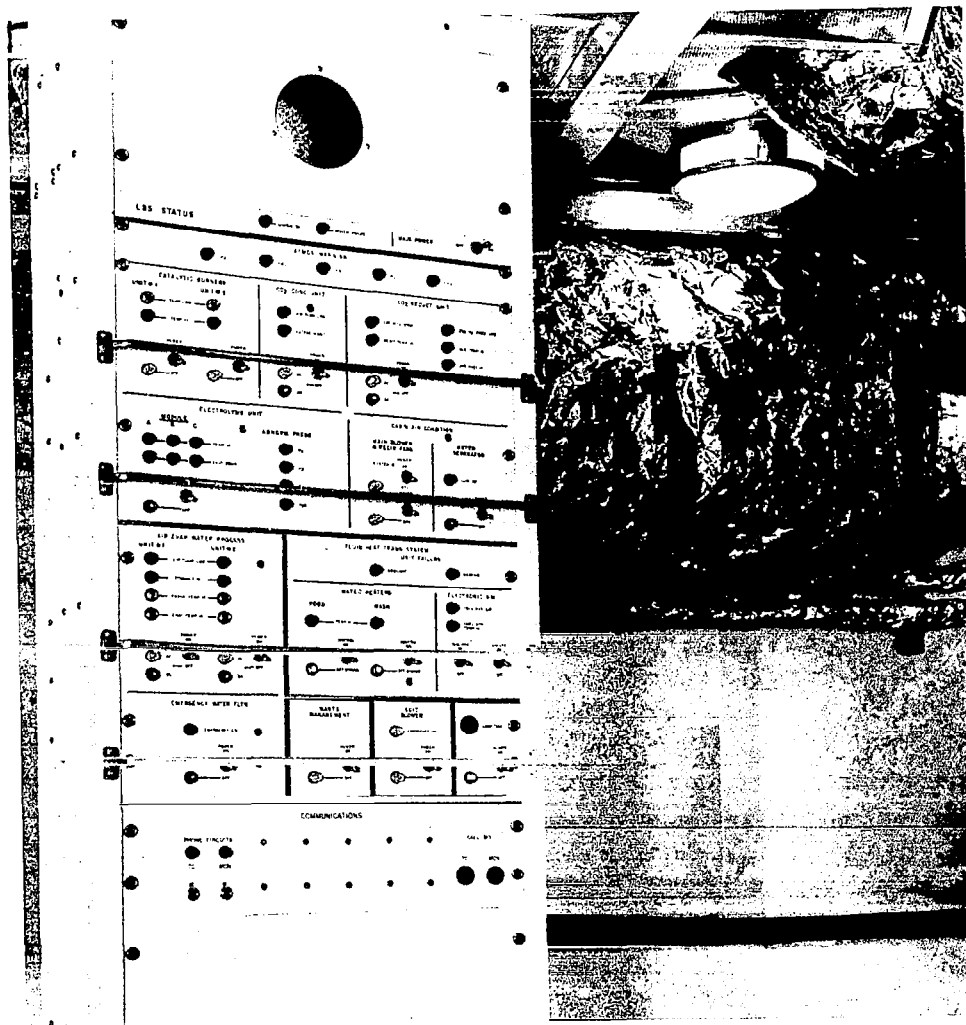


Figure 3.2-52. Operational Status Panel

Two additional operational features were added: (1) a lamp-test circuit, press to light all warning lamps, and (2) audible alarm on/off capability accompanied with an ALARM OFF light. This capability permits deactivating the alarm during extended problem periods.

6.2.7.3 Ground Control Console. The ground control console (Figure 6.2-53) provides a focal point for several major test-control functions. Discussion of these functions includes definition of system considerations. These functions are:

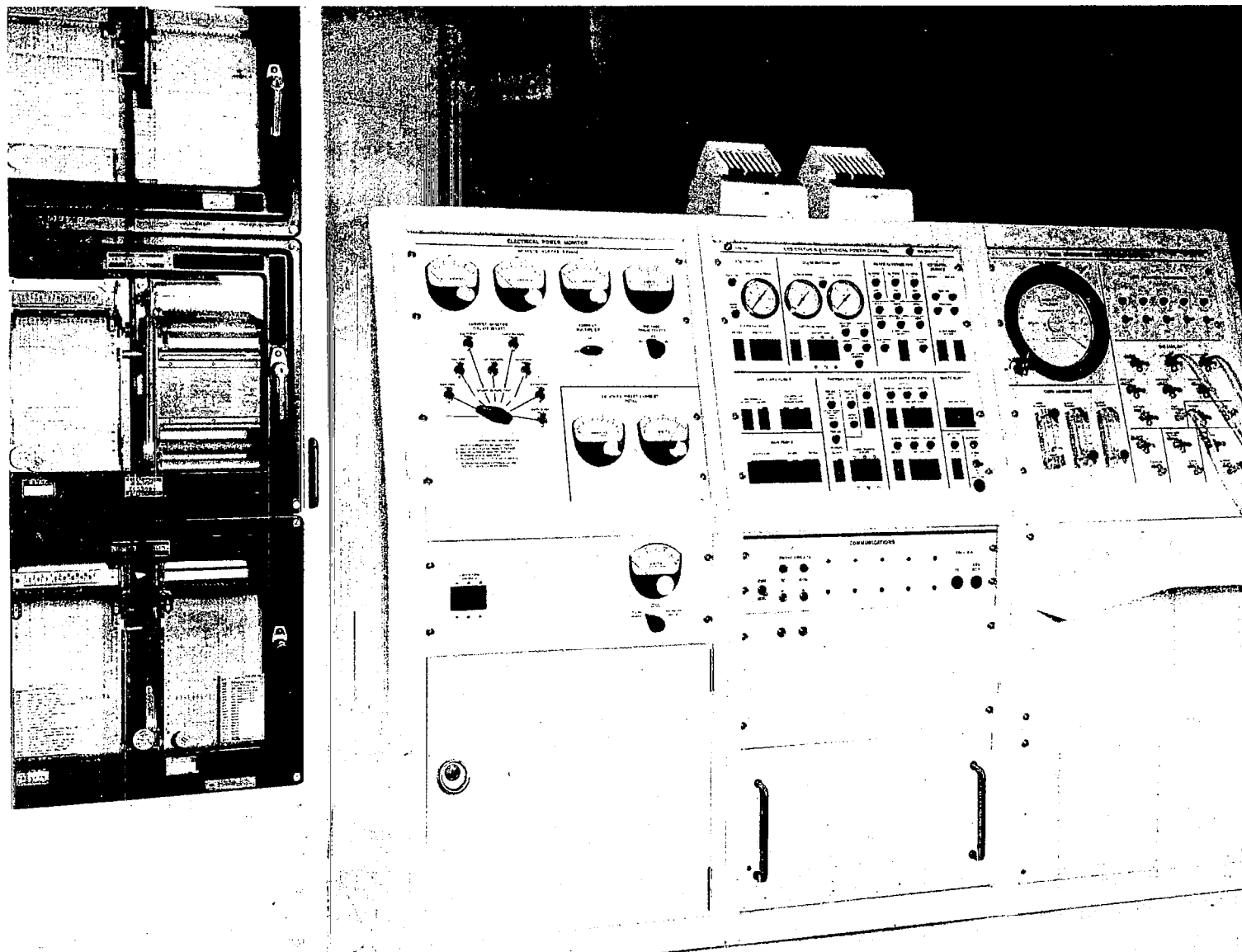


Figure 6.2-53. Ground Control Console

- a. Electrical-power distribution, switching, overload cutoff and monitoring of principal subsystems and test-bed functions.
- b. Operating status indicators for subsystems and selected components.
- c. Cabin pressure monitoring and control.
- d. Sampling circuits for cabin atmosphere and subsystem process loops.
- e. Status indicators for cabin atmosphere.
- f. Ground-to-test-crew communications.

The electrical-power distribution system permits individual subsystem controls at the ground control console, onboard status panel, and equipment panels. Subsystem overload protection is accomplished at the ground control console to minimize potential fire hazards from insulation breakdown. Electrical power is monitored at ground control systems and appropriate equipment panels. (See Figures 6.2-54 through 6.2-57.) The following capabilities are available at the ground control console: (1) main power (115-208v, 400 cps, 3 phase) phase currents of each subsystem and supply voltage, (2) main dc-power (28 vdc) supply voltage and total current, (3) auxiliary (115v, 60 cps) air and coolant electronic heat-load simulator heater voltages and line voltage, (4) a terminal strip and subsystem selection controls are provided to permit use of an external lab-type wattmeter to monitor 400-cps power consumption of individual subsystems, and (5) precision 50-millivolt busses are provided to monitor 28-vdc power consumption per subsystem. This permits time recording to integrate the intermittent nature of the 28-vdc power consumption.

The operating status indicators are the same as the onboard status panel with additional significant quantitative pressures and temperatures for safe unmanned operation.

Cabin Pressure Monitor and Control. Cabin pressure is monitored at the ground control console. Normal O₂ repressurization or enrichment can be accomplished through the valve adjacent to the cabin pressure gage.

The capacity of this valve is limited and as such is not suited for rapid or large changes in cabin pressure. Thus O₂ enrichment following cabin pumpdown is best accomplished by the larger valves associated with direct injection of O₂ from the storage bottles.

Cabin leakage simulation is provided by a cabin-to-vacuum flowmeter and integral valve while makeup is simulated by O₂ and N₂ input flows to the cabin through similar flowmeter valve installations. The flow values are established by manually adjusting the valves integral with the flowmeters.

Figure 6.2-54. Typical 115v, 400 cps Main Power Control Circuitry

6-87

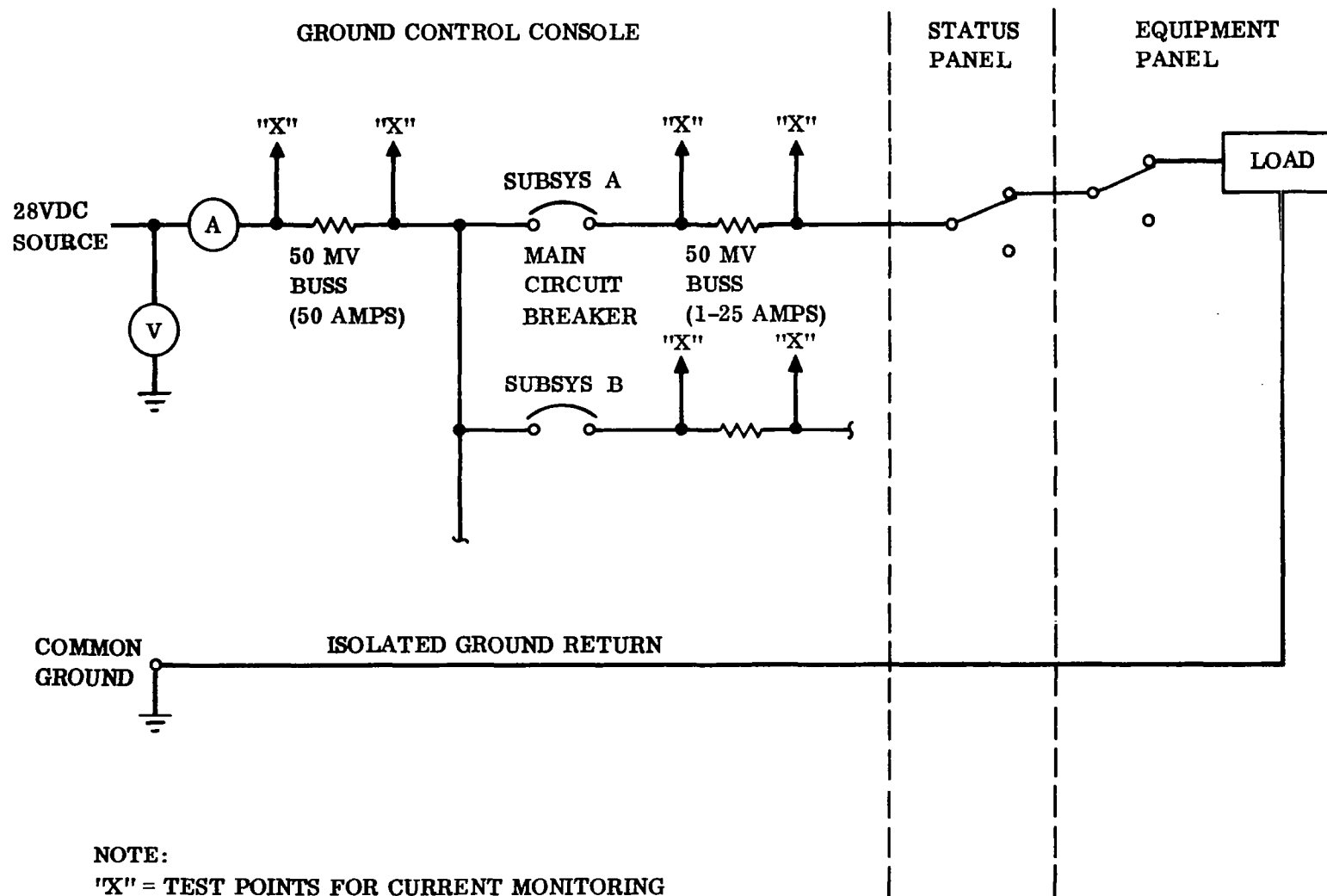
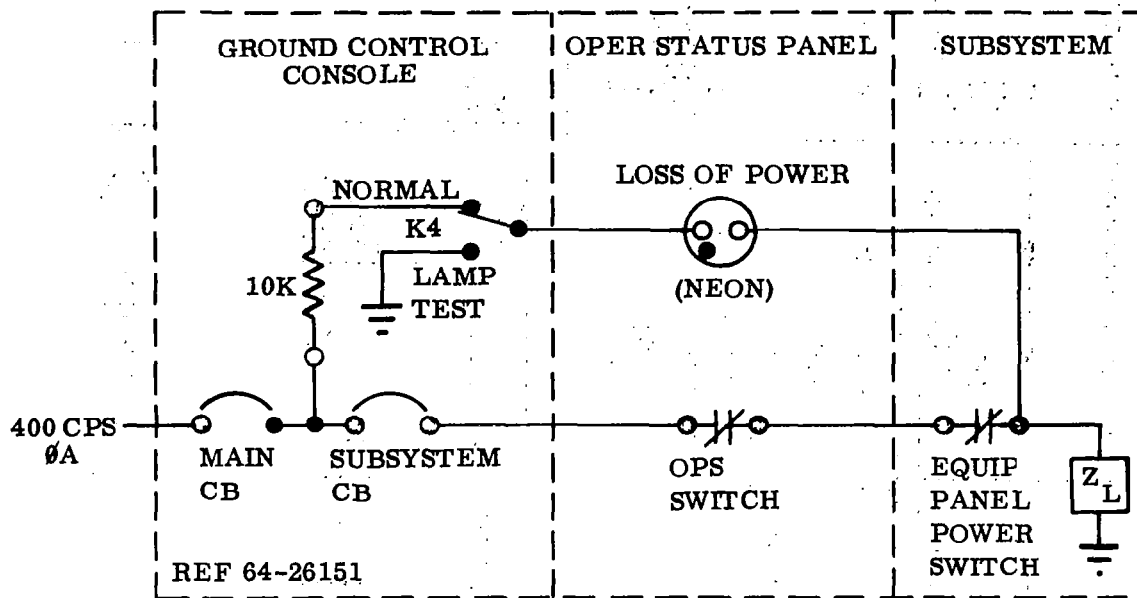


Figure 6.2-55. Typical Main 28-vdc Control Circuit

Figure 6.2-56. Typical Warning Light and Alarm Circuit

TYPICAL AC CIRCUIT



TYPICAL DC CIRCUIT

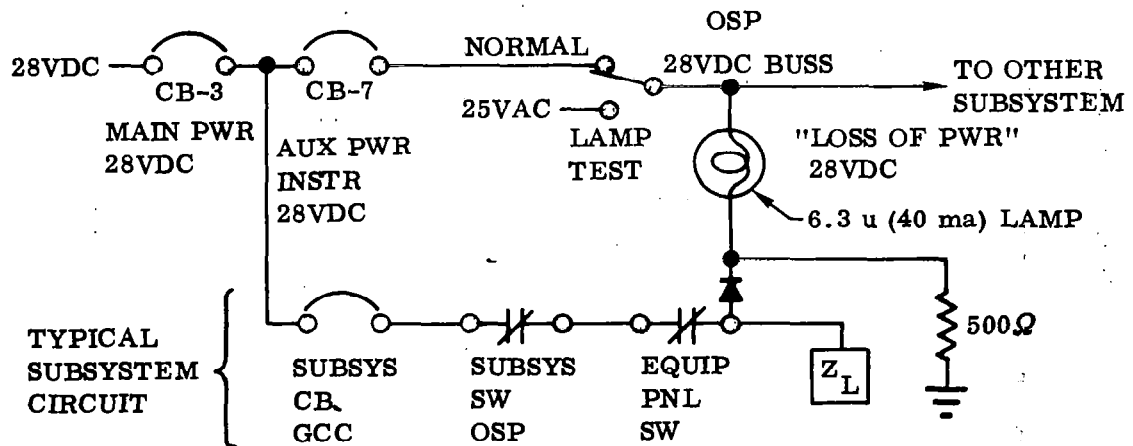


Figure 6.2-57. Loss of Power Warning Circuits

Gas Sampling. Several gas-sample circuits are terminated at the ground control console. (See Figure 6.2-58.) These circuits include both cabin atmosphere and subsystem process-gas sampling. Individual circuit pumps, located with the console, operate continuously to pump a fresh sample for gas analysis. During purging and sampling the unused sample can be returned through the sample-return port for freeze out or continuous monitoring.

Luer lock fittings are provided to permit use of standard medical syringes for taking samples as well as direct transport line interconnections to on-line gas-analysis equipment. The CO₂ accumulator samples do not go through the sample pump. These samples go directly to the gas-sample valve because of leakage and pump diaphragm problems experienced with the high ambient pressure, 30 to 60 psi, of the CO₂ accumulator.

Whenever it is determined that a contamination level exists where further attention is required, a warning-light system can be activated by the operator. The operator then communicates with the test-bed crew and provides quantitative and/or instructional information. The reason for the manually initiated light is to continuously remind both crews of an abnormal condition. (Abnormal conditions could easily exist over protracted time periods and/or involve change of ground test personnel.)

To meet specific requirements the following equipment was utilized.

- a. Gas Chromatograph. A gas chromatograph was to contain four temperature controlled columns, a molecular sieve for fixed gases, a silica gel for CO₂, and a polar and non-polar column for trace contaminant analysis. Valving was to be provided for individual or series operation of columns utilizing a thermal-conductivity detector for fixed gases and a hydrogen-flame detector for trace analysis. Sample handling techniques were to permit capturing of peaks for mass spectrometer or supplementary analysis.
- b. Contaminant Freezeout System. A contaminant-freezeout system was to concentrate trace contaminants for low-level detection. The system was to be designed to process 30 to 120 liters of gas through a freezeout sample tube of approximately 90 milliliters of free space. Freezeout temperature of approximately 165°C was to be controlled by varying absolute pressure of the liquid nitrogen coolant.
- c. A Time of Flight Mass Spectrometer capable of monitoring five gases and scanning the mass spectra from 1-160 for trace contaminants was to be available and used to substantiate data from the gas chromatograph.

To support equipment testing and evaluation, the frequency of sampling and sample sources were increased beyond anticipated requirements. Complicating this problem, the time-of-flight mass spectrometer suffered repeated breakdowns and was not available.

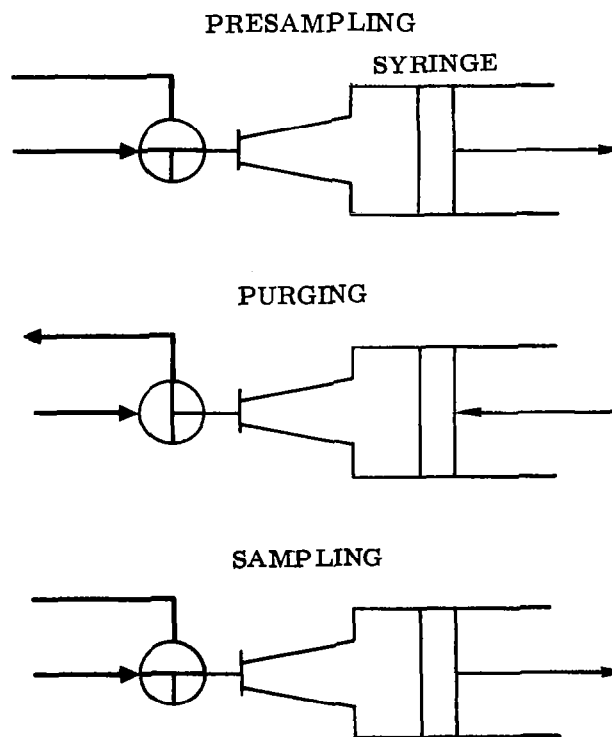
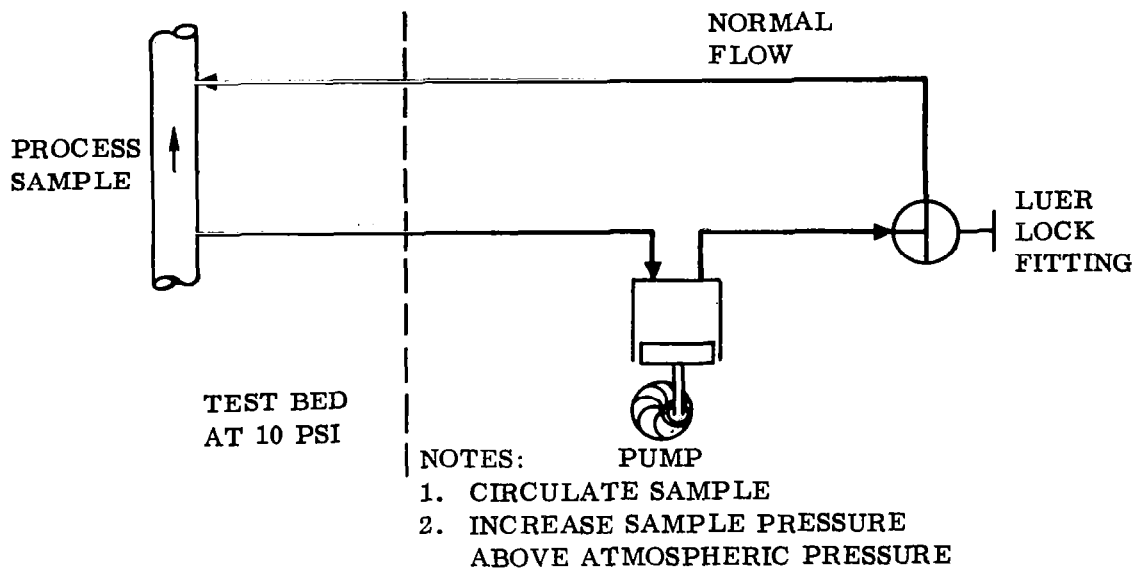


Figure 6.2-58. Gas Sampling Circuits (Typical)

A second chromatograph and infrared-scanning instrument were added for CO₂ and trace-contaminant analysis. The infrared instrument was modified to scan or selectively monitor a specific wavelength for continuous process-loop analysis.

The test program gas-analysis requirements developed to be as listed in Table 6.2-II.

Table 6.2-II. Test Program Gas-Analysis Requirements

SUBSYSTEM	GAS AND RANGE	SENSOR AND DESIRED SAMPLE RATE
CO₂ Concentration Unit		
Zeolite Bed Inlet and Outlet	CO ₂ , 0 to 5 mm Hg	IR Continuous
Zeolite Bed Desorber Outlet	CO ₂ (0 to 100%)	IR Continuous
CO ₂ Accumulator Purity	CO ₂ (50 to 100%)	GC Intermittent
CO₂ Reduction Unit		
Recycle Gas Composition	CO ₂ , H ₂ , CO, CH ₄ , O ₂ and N ₂	IR (CO ₂ Continuous) GC (Intermittent)
Catalytic Burner		
Inlet and Outlet	CO ₂ Reduct Purge Trace contaminants	GC Hourly GC Daily
Charcoal Filter		
Inlet and Outlet	Trace contaminants	GC (Not measured)
Water Electrolysis Unit		
H ₂ Out	Purity (O ₂ and N ₂)	GC (Hourly)
O ₂ Out	Purity (N ₂ and H ₂)	GC (Hourly)
Cabin Atmosphere		
Fixed Gases	O ₂ , N ₂ , CO ₂	GC Hourly
Trace Contaminants	—	GC and IR (Daily)
Gross Trace Analysis	Hydrocarbons	IR (Hourly)

Calibration of analytical equipment was accomplished by using gas standards and periodic cross analysis with the main Convair chemistry laboratory.

Material Out-gassing. During the construction and assembly period of the LSS test bed an out-gassing procedure was developed to determine the volatile gases that would be expected from construction materials. The materials to be tested were placed in a large bell jar and the bell-jar atmosphere flushed until a helium atmosphere existed. The helium and parts being tested were heated to 110°C for 1 hour. The helium was then removed by vacuum through the freezeout unit to collect the volatiles from the materials. The vacuum was held at about 1 torr for 18 hours, at which time the pressure was allowed to rise with filtered helium to about 100 torr, and the bell jar was re-evacuated through a second freezeout trap. The contents of the trap were analyzed by chromatograph and infrared techniques.

Communications. Facility-type intercoms are provided for continuous monitoring of both the living and laboratory compartments. The two sender/receiver units are located on top of the ground control console.

The laboratory unit is located at the status panel. The living area unit is located at the personal hygiene console. In addition, two phone circuits are provided to permit simultaneous communications and/or continuous communications. These circuits are especially helpful for transmission of test data such as gas analysis, the status of an event, etc. Outlet jacks are located on the ground control console, status panel, electrolysis rack, and personal hygiene area. Dynamic headsets are required for this circuit to support the number of sets in use and to overcome the noise level with the operating equipment and simultaneous conversations. Platronics headsets were found to be successful.

6.3 TEST BED DESIGN

6.3.1 CONFIGURATION. The LSS test bed consists of a cylindrical tank with domed ends. (See Figure 6.3-1.) The interior volume of approximately 4150 ft³ is arranged into two levels to accommodate the various functional requirements of the crew.

A composite photograph (Figure 6.3-2) shows the occupied areas of the two levels. The lower level contains most of the life support system equipment, and the upper level houses the sleeping, eating, and personal hygiene facilities.

Passage between levels is via the vertical ladder located against the shell. A safety railing almost encircling the opening in the floor is on the upper level.

The shell of the tank is designed to support a pressure differential of 15 psig in both directions, i. e., pressurized internally to 15 psig or evacuated to 0 psig while in an ambient atmosphere of 15 psia.

The cylinder walls are 1/2-inch-thick carbon steel (ASTM A285 Grade C). The domes are 5/8-inch-thick and of the same material. The outside diameter of the tank is 18 feet, 4 inches. The overall height of the tank (not including supporting columns) is 18 feet.

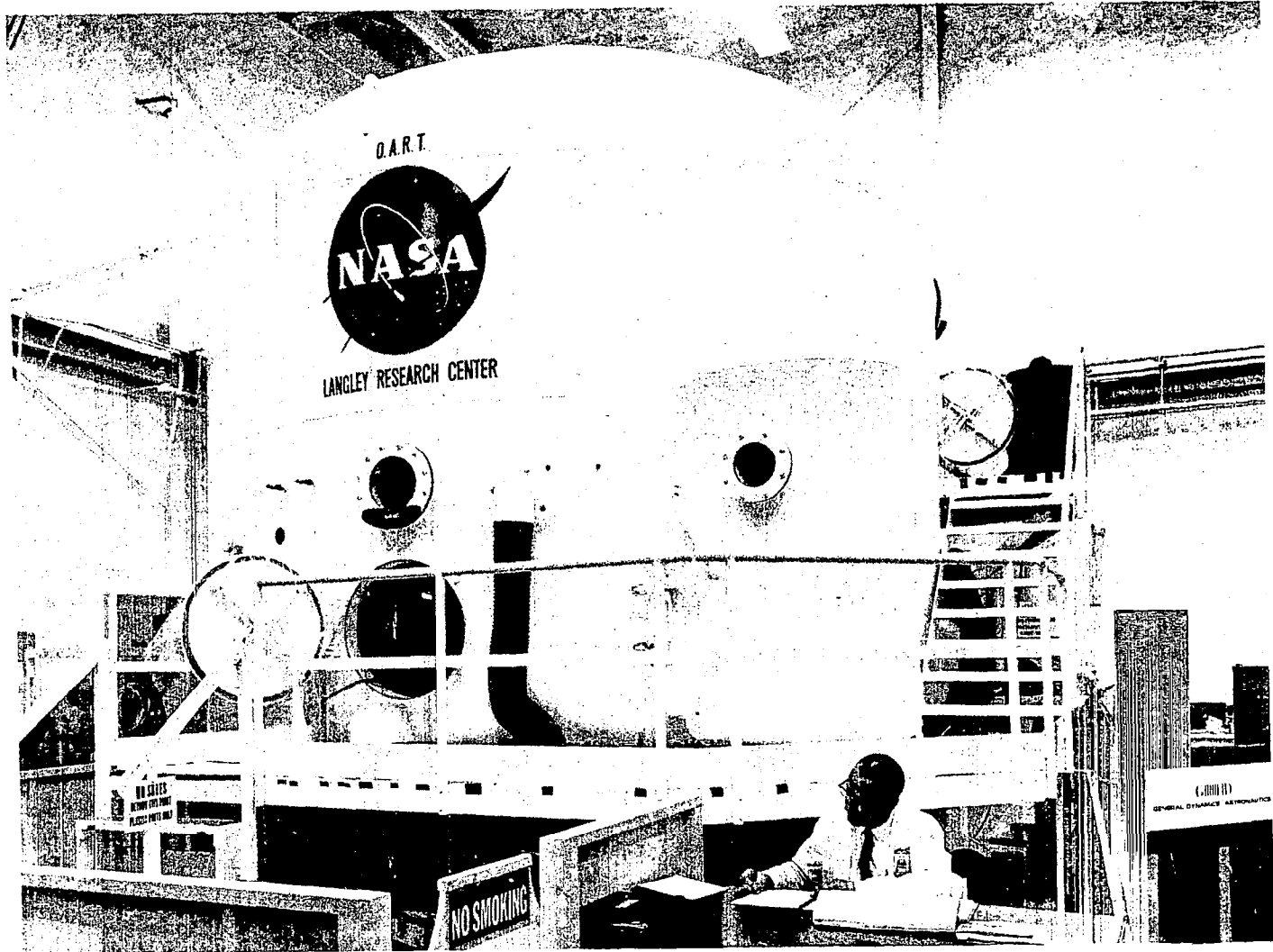


Figure 6.3-1. LSS Test Bed

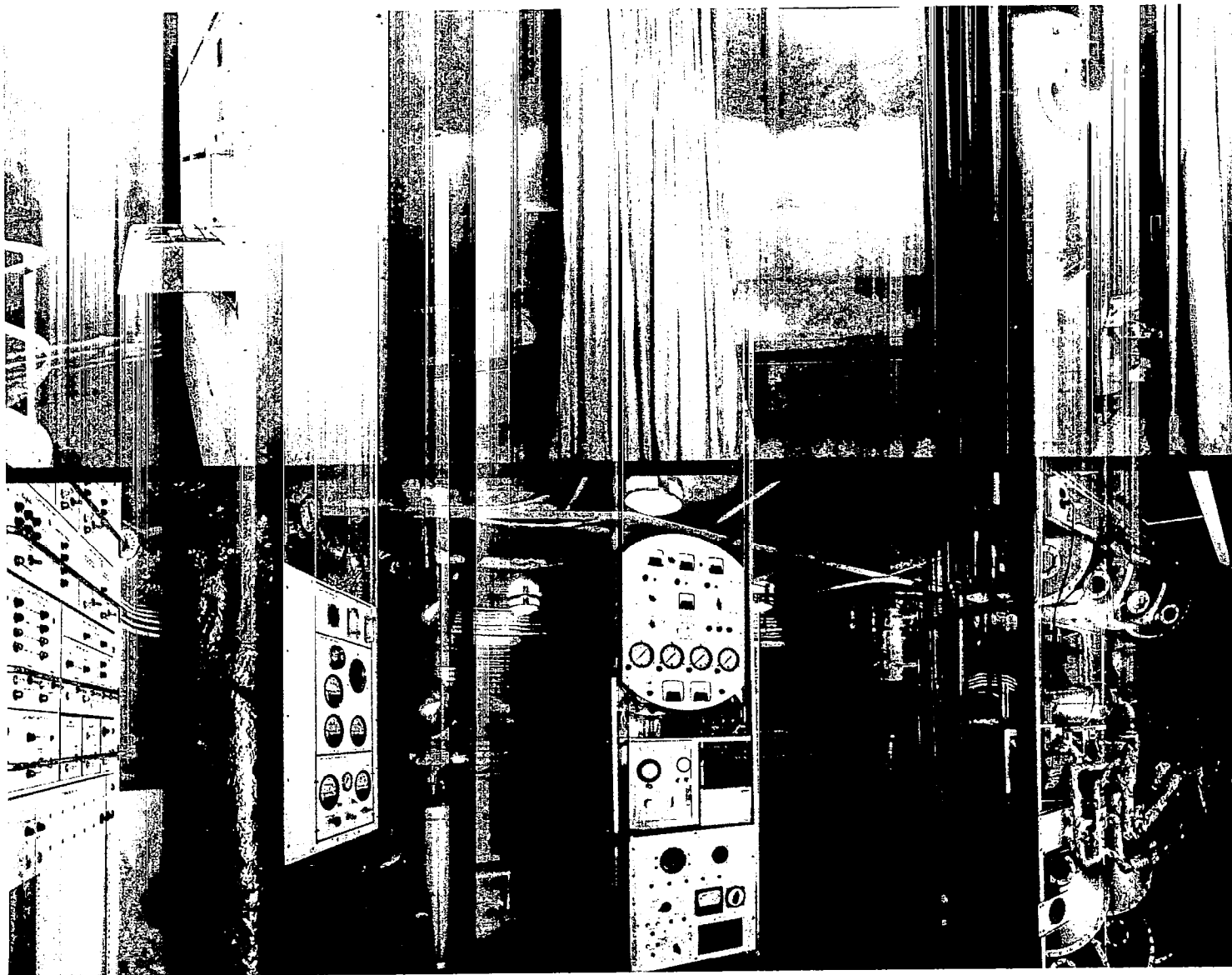


Figure 6.3-2. LSS Test Bed Interior

Support of the test bed is accomplished by 4 columns equally spaced on an 18-foot column circle. The columns are 12-inch diameter, schedule 80, seamless carbon-steel pipe. Each column is approximately 5 feet long and welded to the side of the test bed. The columns add approximately 1 foot to the total height of the test bed.

Normal passage into the test bed is through the air-lock chamber. The air-lock chamber is attached to the external shell of the test bed at the lower level. The air-lock chamber is cylindrical with domed ends top and bottom, and is 4 feet in diameter and 7 feet high. Entry into the air lock from the outside is accomplished through a submarine-type hatch that can be operated from the outside or the inside. Figure 6.3-3 shows the air-lock hatch as the astronaut steps from the air lock onto the platform external to the test bed. An identical hatch connects the air lock to the test bed. Pressurization and depressurization of the air lock can be controlled from the inside of the air-lock chamber. An absolute pressure gauge and a differential pressure gauge that compare the test-bed and air-lock pressures are mounted inside the air-lock chamber.

There are two additional hatches on the test bed, both designed for emergency exit or entrance. The doors are circular, 30 inches in diameter, with handles on both sides (the same as the main doors). One emergency door is located on the lower level and one on the upper level. Emergency vacuum-relief valves are provided inside the test bed adjacent to each emergency door to equalize the internal test-bed pressure and the external pressure.

Penetrations in the shell necessary to transmit pneumatic and electrical signals and atmospheric samples for the LSS are centralized in one 18-inch-diameter plate bolted and mechanically sealed on the lower-level wall. This panel is detailed on Convair Drawing 64-26108, Sheet 4. A blank panel for other possible penetrations is provided on the upper-level wall.

Pressure within the tank is controlled by means of two vacuum pumps that are not a part of delivered system. For quick pulldown of the test bed, a 350-cfm vacuum pump was used. The same pump was used to adjust pressure in the air lock for ingress to and egress from the test bed.

After pulldown with the large pump, pressure is maintained by means of a smaller (~5-cfm) pump that maintains the desired outflow from the cabin to simulate leakage.

In the event that internal pressure drops below a specified crew-safety value, a negative pressure-relief valve opens at a differential pressure of 6.7 psi below the surrounding ambient.

6.3.2 RACKS. The bulk of the life support equipment is located on the lower level of the test bed chamber. Each component of the system is securely attached to one of the formed-aluminum supporting racks.



Figure 6.3-3. LSS Test Bed Air Lock

Approximately two-fifths of the lower-level floor area is reserved for laboratory equipment and furnishings for other than the life support system. Compactness of the LSS in the remaining area had to be compatible with access and maintainability of the equipment. The rack structure is fastened together with nuts and bolts and bolted to the floor and ceiling to provide position flexibility along with rigid structural support. Details of the rack structure are shown on Convair Drawing 64-26117.

6.3.3 ACOUSTICS. The test-bed acoustic treatment was developed to assure effective room-reverberation control over a broad frequency range. Approximately 75 percent of the internal test-bed area is covered with mechanically applied, chemically inert fiberglass, securely encased in fiberglass cloth and lined with perforated-aluminum panels.

The floors are covered with pure-nylon carpeting containing no dye, tuff binder, or jute. The carpeting was thoroughly washed, rinsed, and dried by the manufacturer, and the fiberglass treatment was thoroughly vacuum cleaned upon completion of the installation.

The acoustic treatment is compatible with the requirements of extended-duration missions with respect to potential toxicity, and particulate contamination.

The fiberglass is nonflammable, and the carpeting has a very low surface flammability when used as a floor covering and in the absence of a prolonged or intense ignition source.

6.3.3.1 Acoustic Materials. J-M B010 unbonded B-fiber (0.00010- to 0.00015-inch diameter) noncorrosive boro-silicate fiberglass blankets are mechanically applied to walls and ceiling. Raw batts are tenacious air deposits of long fibers. Blankets are compacted in manufacture to 4-1/2 lb/ft³ density, 2 inches thick, retained by large-mesh iron-wire screen on both sides of the blanket. The blankets are securely encased in Thelco No. 1581 fiberglass cloth, 8-1/2 mil thick, 8.9 oz/yd², 57 × 54 threads/inch. Blankets are nominally 24 × 48 inches, trimmed to fit where necessary. Perforated-aluminum panels are applied over the blankets.

The panels are fabricated from Alcoa 6061-T6 aluminum, Federal Specification QQ-A0327B, condition T. Perforations are 3/32-inch diameter on 3/16-inch staggered centers (33 holes/in.²), providing 23 percent porosity (open area).

The floors on both upper and lower levels are covered with cotton-backed continuous filament nylon carpeting from Berven Carpet Co., mechanically applied. The nylon is DuPont 501, which contains no dye, tuft binder, or jute, and is detergent washed, rinsed, and dried after manufacture. In the lower level, the carpet actually extends beyond the horizontal floor area, covering the fiberglass blanket up the hemispherical section to the vertical section of the cylindrical wall.

6.3.4 FURNISHINGS. In addition to the components and structure related to the life support system, furnishings for personal comfort are provided. These furnishings are located on the upper level of the test-bed chamber.

Four bunks are provided in individual compartments for maximum privacy and isolation of noise. (See Figure 6.3-4.) Vinyl-coated nylon curtains separate each compartment from the rest of the chamber. The bunks are 6 feet in length and designed to contain a polyerethane foam mattress. Under each bunk is a pullout drawer for storage of personal belongings.

The personal hygiene system is located on the upper level. A source of hot water for washing is provided. A shelf for personal toilet articles including sponge, toothbrush, soap, and electric razor are provided for each of four crewmembers.

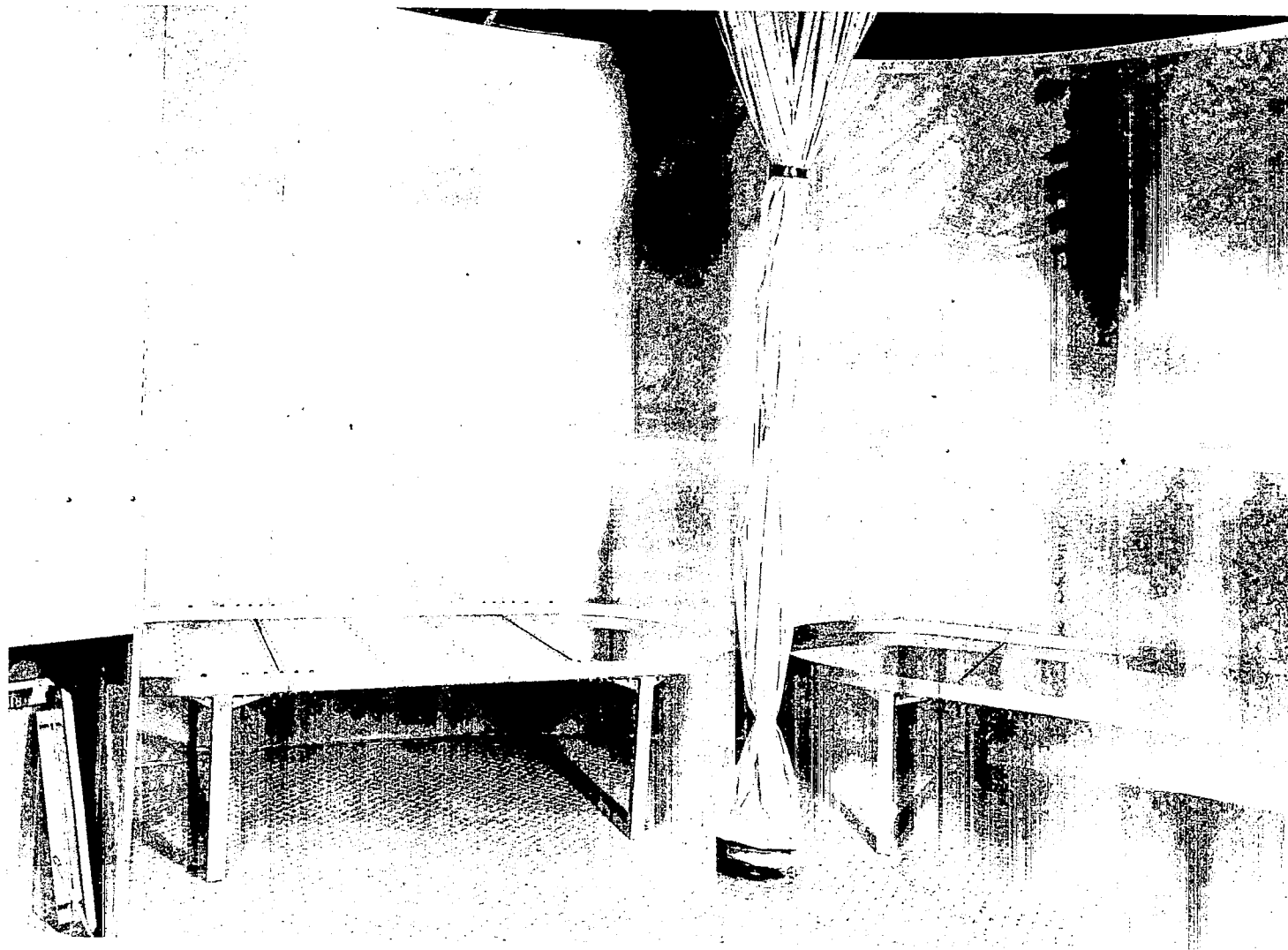


Figure 6.3-4. LSS Test Bed Sleeping Area

SECTION 7

TEST PROGRAM

A detailed test plan was devised at the beginning of the program to assure the timely exercise of informed program control in each phase of system development. The early development status of much of the equipment required some departure from the methodical test plan.

7.1 SOURCE ACCEPTANCE INSPECTION

Source acceptance inspection (SAI) was the official buyoff for all major developmental items. The SAI was conducted by the cognizant Convair LSS project engineer at the vendor facility and witnessed by NASA/LRC. The objectives were to: perform equipment inspection; review data for compatibility and completeness; and verify subsystem operation.

As SAI testing progressed, it became evident that most of the equipment was not fully developed and that scheduled completion dates would not be met. The acceptance test plan was then re-examined and modified for compatibility with the overall program schedule. Acceptance was based on the inherent capability of the equipment to perform the function; knowledge and understanding of the explicit deficiencies; and the capability of Convair to accomplish the necessary modifications.

7.2 CONVAIR FUNCTIONAL CHECKOUT

The Convair functional checkout was to demonstrate proper installation and functional operation of the subsystems as an integrated system within the LSS test bed. Instrumentation and controls were functionally checked, instruments calibrated, and test personnel familiarized with operation and evaluation.

7.3 UNIT PERFORMANCE TESTS

Individual unit performance tests were conducted by the cognizant subsystem engineer to determine that the equipment met systems requirements. The performance test program, due to the state of equipment development, became a test, redesign and re-test improvement program until the equipment proved to be acceptable and reliable.

System interface requirements concurrently underwent modification as heat loads and electrical requirements were more accurately established.

The end results of the unit performance tests were subsystems that had improved stability and reliability and that met the test bed system requirements.

7.4 DEMONSTRATION TESTS

The purpose of this test was to demonstrate for NASA/LRC observers that the integrated LSS installed in the test bed could successfully meet the operational system requirements.

In preparation for the demonstration test, tests were conducted at various levels of systems integration as equipment became operationally available. Thermal controls and heat-transport-fluid circuits were modified to provide stable, integrated system operation.

The successful demonstration tests were monitored by NASA the week of 12 July 1965.

SECTION 8

TEST RESULTS AND DISCUSSION

Systems amenable to source acceptance inspection (SAI) tests were tested at the manufacturer's facility. Functional tests of the installed equipment were then conducted at Convair to verify performance and compatibility to the test bed and other systems, and to establish detailed operating procedures for use in a handbook of operating instructions. Additional evaluation tests were performed as subsystems and components were modified for improvement under CCN No. 5.

All systems were successfully demonstration-tested in a 10-psi cabin on Tuesday, 13 July 1965, and Thursday, 15 July 1965. The electrolysis unit, CO₂ concentration unit, and reduction unit were first connected to each other and operated as an integrated oxygen-regeneration system with the reduction unit in the Bosch mode of operation, and again to demonstrate vacuum desorption and the Sabatier backup mode of operation.

Collection tanks of the water management system were partially filled with urine and used wash water prior to the test, since the test duration was considerably less than the several days needed to establish a stable water inventory from biological processes. Pretreatment and transport operations were tested to demonstrate the functional adequacy of the expulsion and metering equipment, as well as the recovery of potable water from waste liquids.

8.1 THERMAL CONTROL

8.1.1 VENDOR SAI TESTS. Source acceptance inspections (SAI) were conducted at the vendor's facilities on the following two components of the thermal control system.

- a. Fluid cooling and pumping unit (radiator simulator).
- b. Fluid heating and pumping unit (power-system simulator).

The remaining components procured for the thermal control system were accepted on the basis of either (1) performance data developed at the manufacturer's facilities (blowers, valves, etc.) or (2) manufacturer's adherence to detailed design specifications and drawings developed by Convair (cabin air heat exchangers, etc.).

8.1.1.1 Fluid Cooling and Pumping Unit. The SAI of this unit was initiated at C. G. Hokanson Co., Inc., on 29 September 1964. The inspection was conducted in accordance with the Test Procedure, Cooling and Pumping Unit, submitted by C. G. Hokanson Co., Inc., on 8 September 1964 as amended by Revisions D and E, dated 15 and 24 September 1964 respectively.

The inspection was basically conducted in three phases.

- a. System proof pressure test.
- b. Functional tests to demonstrate the operation of critical control and safety devices.
- c. A 15-hour performance test to establish the operating characteristics and capabilities of the unit under various flow and load conditions.

The unit refrigerant (R-22) and coolant (FC-75) circuits withstood the proof-pressure test without exhibiting any deformation or (after minor repair) leaking.

All critical control and safety devices functioned properly and were in acceptable agreement with predicted performance.

The unit demonstrated a design cooling capacity of 57,000 Btu/hr and a pumping capacity of 2070 lb/hr (FC-75) against an external system resistance of 65 psig. (The detailed pumping characteristics of this unit, as developed at the SAI, are shown in Figure 8.1-1.) These performance capabilities exceed the performance requirements as stipulated in the procurement specifications.

Throughout these tests, it was noted that the fluid-temperature control thermostat would frequently make and break erratically. This erratic thermostat operation caused the refrigerant hot-gas bypass solenoid valve to chatter. This noisy operation was attributed to either mechanical vibration or dirty contacts and was not considered to be critical.

The SAI was completed on 2 October, and the unit was accepted for shipment to Convair. The detailed results of this inspection are documented in Final Source Acceptance Inspection of the Fluid Cooling and Pumping Unit at C. G. Hokanson Co., Inc., dated 12 October 1964.

8.1.1.2 Fluid Heating and Pumping Unit. Two source acceptance inspections were conducted on this unit at C. G. Hokanson Co., Inc.

Initial SAI. The initial inspection was started on 20 October 1964. This inspection was conducted in accordance with Heating and Pumping Unit Test Procedure submitted by C. G. Hokanson Co., Inc., on 24 June 1964, as amended by Revisions A and B, dated 8 and 14 July 1964 respectively.

During this SAI, heat-transport fluid (DC-331) was observed continuously leaking from the unit flowmeter. All attempts to eliminate this high-temperature fluid leak proved to be futile. Subsequent discussions with the flowmeter manufacturer's representative disclosed that the meter was not compatible with the intended application.

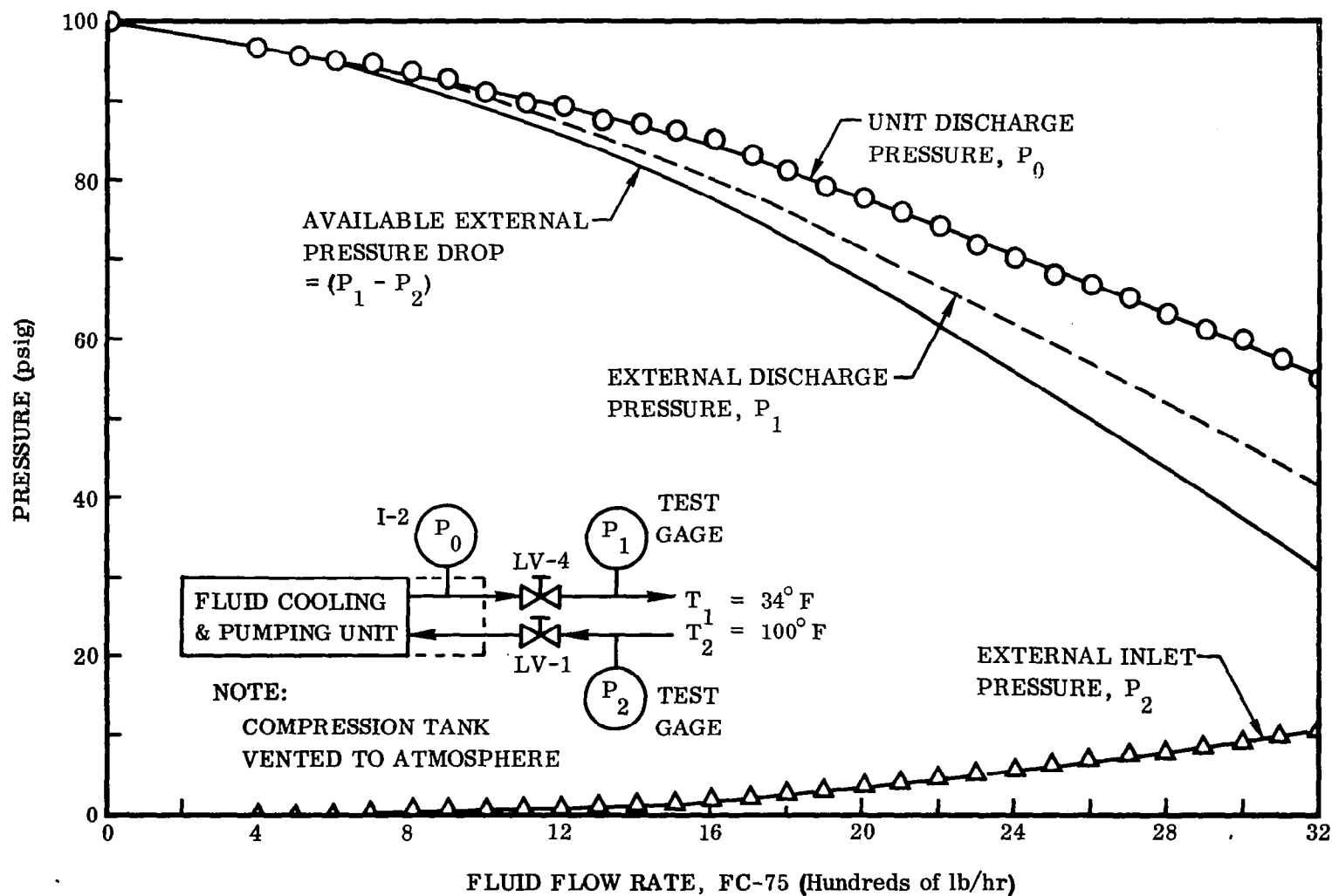


Figure 8.1-1. Fluid Cooling and Pumping Unit

The fluid no-flow cutout switch also failed to demonstrate the desired operating characteristic.

This initial inspection was terminated on 21 August 1964 to permit the manufacturer to take appropriate measures to correct the prevailing deficiencies. The detailed results of this inspection are documented in Initial Source Acceptance Inspection of the Fluid Heating and Pumping Unit at C. G. Hokanson Co., Inc., dated 28 August 1964.

Final SAI. The final SAI was initiated at the vendor's facilities on 5 October 1964. This inspection was conducted in accordance with Test Procedure, Heating and Pumping Unit submitted by C. G. Hokanson Co., Inc., on 8 September 1964 as amended by Revisions D and E, dated 15 and 25 September 1964 respectively.

This inspection was basically conducted in three phases.

- a. System proof-pressure test.
- b. Functional tests to establish the operation of critical control and safety devices.
- c. A 15-hour performance test to establish the operating characteristics and capabilities of the unit under various flow and load conditions.

The unit liquid (DC-331) circuit withstood the proof-pressure test without exhibiting any deformation or (after minor repair) leaking.

All critical control and safety devices functioned properly and were in acceptable agreement with the predicted performance.

The unit demonstrated a design heating capacity of 30,000 Btu/hr (8.7 kw) and a pumping capacity of 800 lb/hr (DC-331) against an external system resistance of 52 psig. (The detailed pumping characteristics, as developed at the SAI, are shown in Figure 8.1-2.) These performance capabilities exceed the performance requirements as stipulated in the procurement specifications.

The unit maintained acceptable control of the fluid-discharge temperature and required only minor manual adjustment to compensate for large variations in load when operating at high fluid-flow rates. However, at low external-flow rates, the unit was unable to maintain the fluid-discharge temperature within the prescribed limits ($390 \pm 10^{\circ}\text{F}$). This was attributed to the low fluid velocity through the heater, which permitted large temperature gradients to develop in the fluid between the heater and the downstream control sensor. At flow rates of approximately 100 lb/hr, the magnitude of this gradient was sufficient to cause the fluid temperature within the heater to exceed the high-temperature setting in the cutout thermostat located within the heater housing. Continued operation under these conditions permitted this cutout

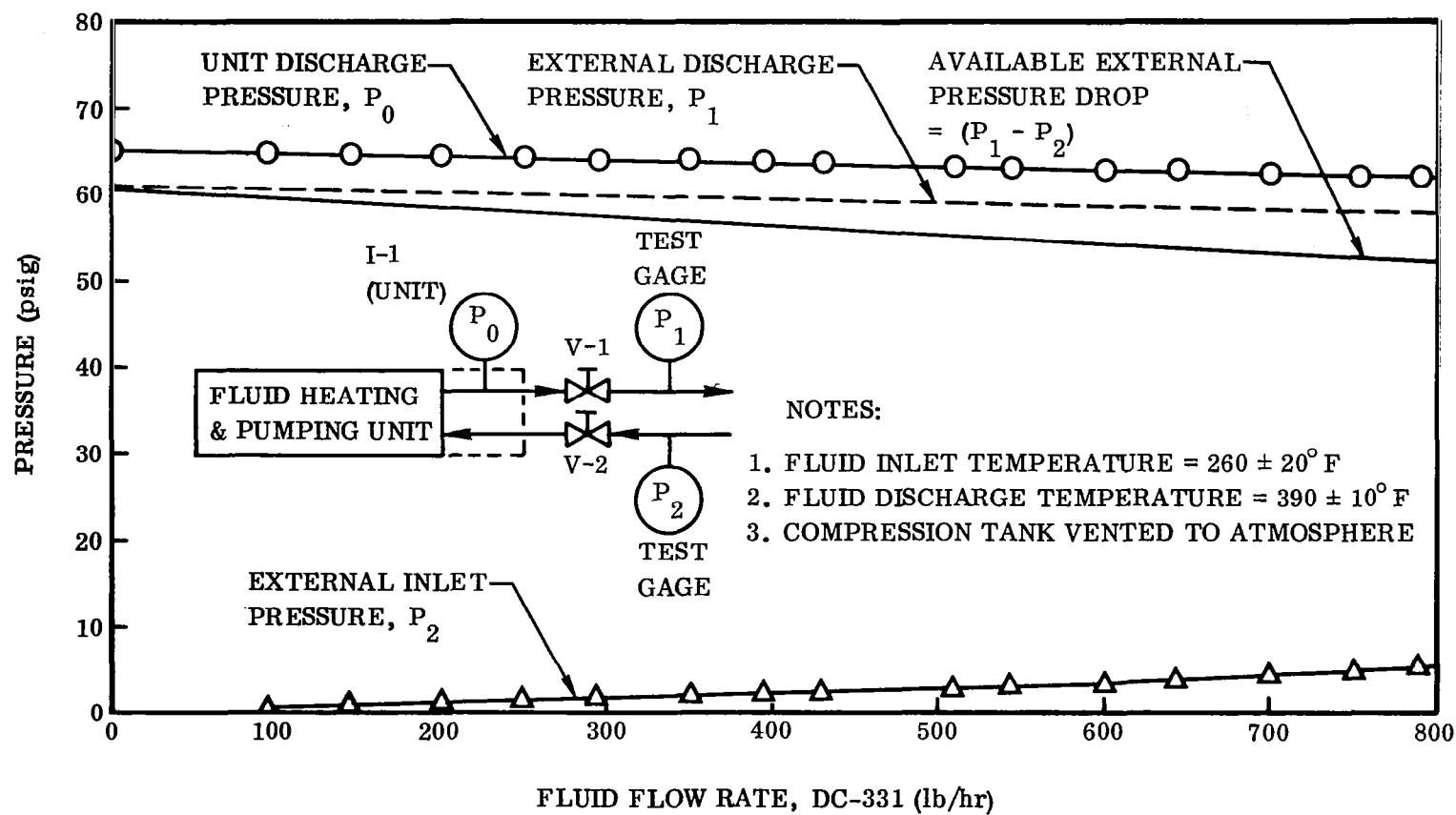


Figure 8.1-2. Fluid Heating and Pumping Unit

thermostat to assume control of the fluid temperature and cycle the electric input to the heater to produce fluid temperatures (within the heater) corresponding to those required to open and reset the thermostat. This on-off heater operation resulted in a cyclic unit fluid-discharge temperature of $390 \pm 30^\circ \text{F}$. However, it was not anticipated that the unit would be operated at this low flow rate in actual application. Furthermore, if a low flow rate were required, this cyclic heater operation could be avoided by properly readjusting the internal bypass and pump pressure-relief valves.

Throughout the test, DC-331 was observed to intermittently leak from the pump-shaft seal. However, this seal would always reseal itself and hence did not represent any major problem.

The SAI was completed on 9 October and the unit was accepted for shipment to Convair. The detailed results of this inspection are documented in Final Source Acceptance Inspection of Fluid Heating and Pumping Unit at C. G. Hokanson, Co., Inc., dated 14 October 1964.

8.1.2 CONVAIR FUNCTIONAL CHECKOUT. Functional checkouts were conducted on all major components and subsystems of the thermal control system.

8.1.2.1 Air Circuit. A functional checkout of the air circuit (System A) was conducted on 21 November 1964 in accordance with Procedure for Functional Test and Preliminary Adjustment of the Thermal Control Air Circuit, dated 20 November 1964.

The primary objectives of this checkout were:

- a. To ensure all interface electrical connections were properly made.
- b. To demonstrate that the main blower has sufficient capacity to deliver the design air-flow rate to each module.
- c. To demonstrate the operation of the air bypass-damper control system.
- d. To check the effectiveness of the installed vibration isolators and flexible-duct joints.

The air distribution was balanced between the living and laboratory modules in direct proportion to the anticipated average sensible heat loads in each of these zones. This balancing required that the total cabin air-flow rate be adjusted to 270 cfm with 73 cfm of this flow rate being delivered to the living module and the remaining 197 cfm going to the laboratory module. To accomplish this, only a 3-inch balancing orifice was required. This orifice was installed in the 6-inch branch duct to the central diffuser in the living module. The measured resistance of this balanced circuit was approximately 7.5 inches of water under standard atmospheric conditions with the bypass damper in the closed position.

Additional tests also indicated that the total air-flow rate varied by less than ± 10 percent from the design value (300 cfm) when the air bypass damper was traversed through its complete arc. Preliminary measurements also indicated that the air-flow rate through each eyeball diffuser (in the bunk areas) varied between 9-16 cfm depending upon the number of diffusers that were opened and the air bypass damper position.

All of the above characteristics were in good agreement with the initial design estimates.

The damper actuator operated well in response to changes in the temperature selector setting and required approximately 50 seconds to traverse its complete stroke (160 degrees).

The installed vibration isolators and flexible-duct joints transmitted excessive high-frequency mechanical vibrations to the remainder of the system. This deficiency was subsequently corrected with the installation of softer isolators and flexible-joint materials.

The results of this checkout are also summarized in Convair Memo Completion of Functional Checkout - Thermal Control Air Circuit, dated 23 November 1964.

8.1.2.2 Heat-Transport Fluid Circuits. Functional checkouts were conducted on the following components of the liquid coolant and process heat circuits.

- a. Coolant fluid heater (electronic equipment simulator).
- b. Liquid coolant and process heat distribution circuits.
- c. Fluid cooling and pumping unit (radiator simulator).
- d. Fluid heating and pumping unit (power system simulator).

The results of these checkouts are summarized in the following subsections.

Coolant Fluid Heater (Electronic Equipment Simulator). A functional checkout of the coolant fluid heater was performed during 11-13 November 1964 in accordance with Procedure for Functional Test, Coolant Fluid Heater, dated 20 November 1964. The primary objectives of this checkout were:

- a. To demonstrate the structural integrity of the unit.
- b. To demonstrate the performance of the high-temperature warning and limit thermostats.
- c. To check the calibration of the variac control.

After initial adjustments, the unit withstood a static proof pressure of 100 psig without leaking or exhibiting any apparent deformation.

During dynamic testing, the high-temperature warning thermostat energized the external warning circuit at a fluid-discharge temperature of $161 \pm 2^\circ\text{F}$. This temperature is approximately 10°F higher than the discharge temperature originally specified but is acceptable for the application intended.

The high-temperature limit (cutoff) thermostat also proved to be out of calibration. The temperature-selector dial on this adjustable unit had to be set at 152°F before the thermostat would de-energize the heater electrical circuit at a fluid-discharge temperature of 175°F as prescribed in the unit specification. The magnitude and direction of this error are considered to be sufficient to justify the repair or replacement of this safety control.

The variac performed well and demonstrated linear control of the output voltage over its entire range.

The detailed results of this checkout are given in Convair Memo Completion of Functional Test - Coolant Fluid Heater, dated 23 November 1964.

Heat-Transport Fluid Distribution Circuits. Functional checkouts of the liquid coolant and process heat distribution circuits were conducted on 27 November 1964 in accordance with Procedure for Functional Checkout and Preliminary Adjustment, Liquid Thermal Control Circuits, dated 27 November 1964. The primary objectives of this preliminary checkout were:

- a. To ensure that the installed circuit routings agreed with the designed distribution system.
- b. To ensure all manual balancing and service valves functioned properly and no blockages were present in the lines.
- c. To demonstrate the structural integrity of the circuit.

The heat-transport fluid circuits were checked for proper routing and then purged with nitrogen gas to ensure continuity. The liquid-coolant and process-heat circuits were then pressurized with a nitrogen-Freon gas mixture to a pressure of 145 psig and 95 psig respectively, and checked for leaks with an ultrasonic leak detector and subsequently with an electronic halogen leak detector. All leaks in the circuits were repaired during the course of inspection.

The circuits were then subjected to a static proof-pressure test for a period of 1/2 hour to ensure that no leaks went undetected.

The results of this preliminary checkout are also given in Convair Memo Completion of Functional Checkout - Liquid Thermal Control Circuits, dated 3 December 1964.

During the above described checkout, numerous LSS components were either not yet available or were not installed in the circuits. Therefore, the liquid pressurization and dynamic-flow balancing of these circuits were deferred until additional LSS components were installed. As these components were installed and circuit modifications were made, the affected branch circuits were independently leak-tested utilizing only liquid pressurization in order to expedite the procedure.

Fluid-Cooling and Pumping Unit. The unit, as received from the vendor, had developed leaks in the refrigerant system during shipment and lost the refrigerant (R-22) charge in one of the two parallel refrigerant circuits. After the unit was installed and connected to the coolant circuit, these leaks were located and repaired, and the circuit was recharged with refrigerant. A brief functional test was then conducted to ensure that:

- a. All interface connections (FC-75, water, and electrical) were properly made.
- b. All controls and components functioned properly, and no hidden damage occurred during shipment or installation.

The unit performed satisfactorily and demonstrated the same apparent characteristics exhibited during the source acceptance inspection at the vendor's facilities.

Fluid-Heating and Pumping Unit. Upon receipt of the unit, it was visually inspected to determine if any apparent damage had been incurred during shipment. The unit was then installed and connected to the process-heat circuit and subjected to a brief functional checkout to ensure that:

- a. All interface connections (DC-331, water, and electrical) were properly made.
- b. All controls and components functioned properly and no hidden damage occurred during shipment or installation.

The unit performed satisfactorily and demonstrated the same apparent characteristics exhibited during the source acceptance inspection at the vendor's facilities.

8.1.2.3 Water-Separator Performance. Of the three separator configurations evaluated in the test bed during the test program conducted at Convair, the final configuration was found to have 50-percent better efficiency than the original configuration when installed for the 10-psia demonstration test of 15 July 1965 (Table 8.1-I). A considerable water carry-over was re-evaporated in the discharge duct during all tests. When an allowance is made for this re-evaporation, the apparent efficiency of the installation is significantly better than the efficiency of the separator alone. The apparent efficiency attained by the straight-baffle configuration was 95.5 percent, primarily because the reduced cabin pressure permits a greater absolute humidity in the discharge duct.

Table 8.1-I. Cabin Air-Water Separator Test Results

DATE	5 January 1965	8 February 1965	15 July 1965
CONFIGURATION	Chevron Packing	"V" Baffle	Straight Baffle
CABIN PRESSURE, (psia)	14.7	14.7	10.0
Inlet Duct			
Air flow, lb/hr	1630	1192	756
Dry bulb temperature, °F	71.5	77.5	64.3
Wet bulb temperature, °F	60.5	60.9	49.9
Reliability humidity, %	54.0	37.4	59.5
Absolute humidity, lb/lb dry air	0.00885	0.00755	0.0109
Total moisture input, lb/hr	14.40	9.00	8.25
Heat Exchanger Discharge			
Dry bulb temperature, °F	42.5	41.3	32.0
Wet bulb temperature, °F	42.5	41.3	32.0
Reliability humidity, %	100	100	100
Absolute humidity, lb/lb dry air	0.00573	0.00548	0.00545
Water vapor output, lb/hr	9.35	6.54	4.13
Water condensed, lb/hr	5.05	2.46	4.12
Separator			
Water separated, lb/hr	1.28	1.36	1.52
Water trapped, lb/hr	0.17	0.06	0.07
Water leakage, lb/hr (estimated)	0.50	0.18	Trace
Discharge Duct			
Dry bulb temperature, °F	48	46	44
Efficiency, % = $100 \times \frac{\text{water separated}}{\text{water condensed}}$	25.4	55.2	36.8
Apparent Efficiency, % = $100 \times \frac{\text{water separated}}{\text{water removed}}$	65.5	85.0	95.5

The static, porous-plate, cabin air-water separator proved to be leakage-prone throughout the entire program. The sintered metal is delicate and easily damaged in fabrication and handling, and the durability of the plate-to-frame bond remains a question. In addition, long-term testing is likely to reveal other expected problems such as corrosion and degradation of plate porosity.

These known and suspected shortcomings of this static separator justify study of other static-separation techniques in conjunction with serious consideration of a rotating dynamic separator for cabin air systems.

8.1.3 CONVAIR SYSTEM EVALUATION

8.1.3.1 Thermal-Control Air Circuit. During the initial phases of integrated testing, it became apparent that the cooling capacity of System A was inadequate to satisfy the cabin cooling requirements. This system was designed to provide a minimum sensible cabin air cooling capacity of 5500 Btu/hr and demonstrated a sensible capacity in excess of 7000 Btu/hr while maintaining a cabin air temperature of 68°F at a cabin pressure of 10 psia. These sensible cabin cooling capacities were well in excess of those that should have prevailed, based on the estimated thermal characteristics submitted by the LSS component manufacturers.

Subsequent analysis of the data accumulated during these tests indicated that the actual cabin air sensible cooling load was approximately 16,560 Btu/hr. This increase is primarily attributed to heat loads introduced by LSS components that were frequently an order of magnitude larger than initially predicted by the manufacturers.

Due to the size of the task and time limitations, it was impractical to modify the existing circuit (System A) to accommodate the increased load. Therefore, a second air circuit (System B) was installed in the laboratory module. This system has a design cabin sensible cooling capacity in excess of 11,000 Btu/hr and provides sensible cooling to the laboratory module.

The System A distribution circuit was then rebalanced to divert additional cooling to the living module. This rebalancing was accomplished by interchanging the central-supply diffusers and balancing orifices between the laboratory and living modules of the test bed. With System A thus rebalanced, 190 cfm was delivered to the living module while the remaining 65 cfm was diverted to the laboratory module.

During the final demonstration (13 July 1965), this system demonstrated that it could maintain air temperatures in the living and laboratory modules of 67.5 and 80°F respectively. The laboratory module air temperature was well in excess of the 68°F prescribed in the system performance specifications. This apparent lack of cooling capacity in the laboratory module was attributed to the low coolant flow rate (700 lb/hr) through the System B heat exchanger.

During the subsequent demonstration (15 July 1965), the aqueous propylene glycol solution was diluted to 27-percent propylene glycol (by volume) to reduce the coolant-pumping power factor and hence permit an increased coolant flow rate to the System B heat exchanger. During this test, the coolant flow rate to the System B heat exchanger was increased to 910 lb/hr and the system maintained an air temperature of 64-65°F in both the laboratory and living modules. However, this was accomplished with the CO₂ reduction unit operating in the Sabatier mode, and with the water recovery units, water heaters, catalytic burners, and electrolysis unit not in operation. It is estimated that the heat reflected by these components in normal operation would increase the observed laboratory module air temperature by 2 to 4°F. It then appears feasible that, by appropriately rebalancing the system air distribution, this increased load could be absorbed by the existing thermal control air circuit without producing cabin air temperature in excess of the 68°F prescribed in the system performance specifications.

During these demonstration tests, humidity condensate that formed within the System A heat exchanger was removed from the system by both the cabin air-water separator and a drain line connected to a water trap downstream of the separator. This condensate-collection system essentially removed all of the liquid from the air stream. Data accumulated during these tests indicate that the system, as described, was capable of maintaining the cabin air relative humidity within the prescribed limits of 40-60 percent when the cabin was occupied by a four- to six-man crew performing normal test and observation functions.

However, the indicator used to establish the prevailing cabin relative humidity was suspected of error either in its calibration or due to its location on the environmental control performance panel, which did not necessarily expose the instrument to a representative cabin environment. Therefore, the foregoing data should be considered to represent only an apparent humidity-control capability and should not be interpreted as representing the true performance characteristics of the installed system. The System A air-distribution system introduced the conditioned air into the occupied regions of the laboratory and living modules in a manner that was conducive to the crew comfort. System B, as originally installed, introduced the total conditioned air flow rate (700 cfm) through a single deflection (vertical vane) diffuser located above the atmospheric control performance panel in the laboratory module. The air thus introduced produced objectionable air velocities in the normally occupied regions of the module. This condition was subsequently minimized although not eliminated with the installation of a double-deflection grille.

8.1.3.2 Liquid-Coolant Circuit. The heat-transport fluid originally used in this coolant circuit was FC-75. However, during the system tests subsequently conducted, it was observed that this clear fluid leaked easily and evaporated rapidly when exposed

to the atmosphere. Hence, small leaks could not be visually located. Furthermore, no practical method of leak detection could be developed by either Convair or the fluid manufacturer (Minnesota Mining and Manufacturing Company). Therefore, due to these characteristics and the cost of replacement fluid, it was decided to discard the FC-75 and use aqueous propylene glycol (40-percent propylene glycol by volume). This composition was subsequently changed to 27-percent propylene glycol (by volume) to reduce the pumping power requirements.

It should be noted that no change in component performance characteristics was observed or could be directly attributed to this change in fluids.

Coolant-Fluid Heater. Performance tests were conducted on the coolant-fluid heater and electrical-input control (variac) during the initial phases of the non-integrated systems testing to determine the heating capacity of the unit corresponding to each setting on the variac scale.

The heating capacity of the variac-heater combination for a range of variable scale readings of 10 to 100 percent is shown in Figure 8.1-3. This combination demonstrated a maximum heating capacity of 7000 Btu/hr (2.05 kw) with no measurable heat loss through the heater housing.

It should be noted that these tests were conducted using FC-75 as the heat-transport fluid. However, no significant changes in these results should be expected when employing aqueous propylene glycol solutions.

Fluid-Cooling and Pumping Unit. During the early phases of the test program, it was noted that the solenoid valves in the refrigerant system hot-gas bypass lines were operating erratically during the first few seconds of each opening and closing operation. This operation was attributed to two causes.

- a. The installation of improperly selected solenoid valves in the hot-gas bypass lines.
- b. Vibration of the fluid-temperature control thermostat, which activates the hot gas solenoid valves, caused by mechanical components and the impingement of the fluid stream on the thermostat sensor.

This situation was corrected with the installation of (1) properly selected hot-gas bypass solenoid valves, and (2) a time-delay relay in the thermostat circuit to delay the erratic thermostat make and break signals to the hot-gas solenoid valves for a period of approximately 4 seconds. These modifications resulted in a clean, quiet operation without measurably sacrificing the unit temperature-control capability.

Also, during these tests, it was noted that a significant amount of particulate matter was being introduced into the liquid-coolant stream and was clogging the

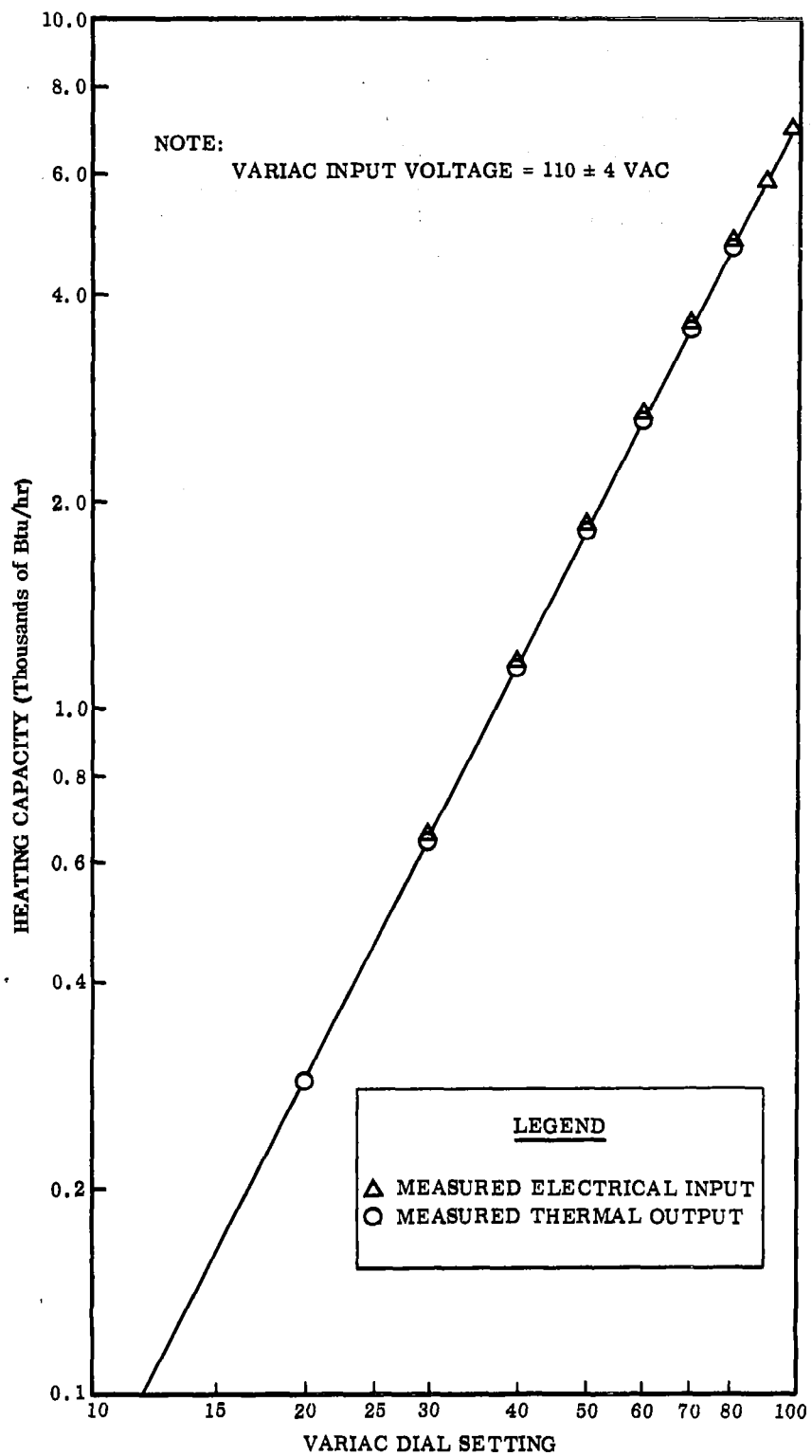


Figure 8.1-3. Coolant Fluid Heater Heating Capacity

fluid strainer, thus limiting the unit pumping capability. This particulate matter was later identified as rust that had developed in the unit compression tank as a result of operating the unit with the tank vented to atmosphere. The remaining rust was flushed from the system, and the unit was subsequently operated with a sealed compression tank to prevent recurrence of this situation. The limited-capacity fluid-strainer element was also removed from the unit, and the filtering function was accomplished by large-capacity filters located in the external coolant circuit downstream of the unit.

During the final demonstration tests, the unit demonstrated that it had sufficient cooling capacity to satisfy the system cooling requirements when all LSS components were operating simultaneously. Throughout these tests the unit maintained a constant fluid (aqueous propylene glycol) discharge temperature of $30 \pm 1^\circ\text{F}$ and demonstrated a pumping capacity of 1420 ± 10 lb/hr against an external system resistance of 88 ± 1 psig. The refrigerant system pressure profile and unit electrical energy consumption corresponding to these performance characteristics are listed in Table 8.1-II.

Liquid-Coolant Distribution Circuit. Numerous changes were made in the coolant distribution to accommodate the changing thermal requirements of the various LSS components and subsystems. The final distribution system installed in the test bed is as illustrated in Figure 6.2-3.

During the final demonstration test (13 July 1965), the coolant fluid (aqueous propylene glycol - 40-percent propylene glycol by volume) was distributed to the LSS components at the flow rates illustrated in Figure 8.1-4. The distribution system, so balanced, was receiving a total fluid-flow rate of 1420 lb/hr and exhibited total system resistance of 88 psig. All of the LSS components and subsystems, with the exception of the System B air circuit, performed satisfactorily. However, the System B cabin air heat exchanger was not receiving sufficient coolant flow to produce the cooling capacity required to satisfy the laboratory module air cooling requirements.

To rectify this deficiency in capacity, the aqueous propylene glycol mixture was diluted to 27 percent (by volume) to reduce its pumping power factor and the total coolant flow rate from cabin air Heat Exchanger A was delivered to Heat Exchanger B. The resulting flow distribution thus achieved was identical to that illustrated in Figure 8.1-4 except that Heat Exchangers A and B were receiving a flow of 910 lb/hr.

During the final phase of the demonstration test (15 July 1965), this rebalanced distribution system was capable of producing the cooling capacity needed to satisfy the cabin air cooling requirements. However, the increased coolant-flow rate to Heat Exchanger B increased the total system pressure drop to 100 psig while reducing the total coolant-flow rate of 1290 lb/hr.

It is readily apparent from the above characteristics that the resistance of the cabin air heat exchangers controls the system pressure drop. During earlier tests, the magnitudes of the pressure drops introduced by these heat exchangers and the

Table 8.1-II. Performance Characteristics, Fluid-Cooling and Pumping Unit, 13 July 1965

FLUID CIRCUIT*		
FLOW RATE (lb/hr)	DISCHARGE TEMPERATURE (°F)	DISCHARGE PRESSURE (psi)
1420 ± 10	30 ± 1	88 ± 1

REFRIGERANT-CIRCUIT PRESSURES (psi)					
SYSTEM A			SYSTEM B		
COMPRESSOR		EVAPORATOR	COMPRESSOR		EVAPORATOR
SUCTION	DISCHARGE		SUCTION	DISCHARGE	
38	202	46	25	198	46

ELECTRICAL-ENERGY REQUIREMENTS (Amp)**					
PUMP ONLY			COMPLETE UNIT		
PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
1.2	1.0	1.0	13.0	11.5	11.5

* Aqueous Propylene Glycol (40-Percent Propylene Glycol by Volume).

** At 440-volt, 3-phase, 60-cps operation.

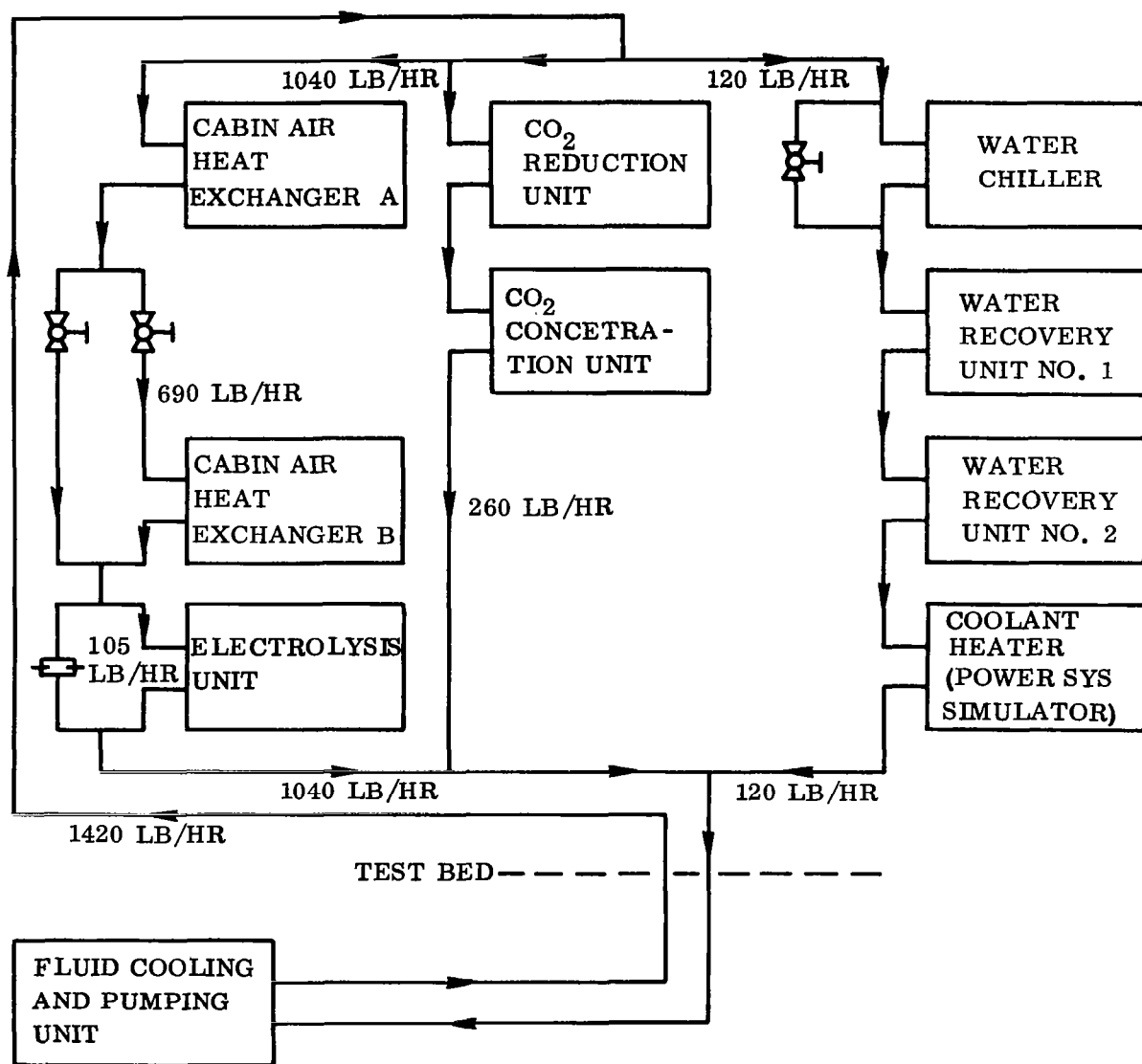


Figure 8.1-4. Coolant Fluid (Propylene Glycol) Circuit Flow Distribution

connecting fluid lines were determined for a 40-percent aqueous propylene glycol solution and are summarized for a fluid-flow rate of 1000 lb/hr in Table 8.1-III.

Table 8.1-III. Pressure Drop for 1000 lb/hr Fluid-Flow Rate

COMPONENT OR FLUID LINE	PRESSURE DROP (psig)
Line From Fluid-Cooling and Pumping Unit to Heat Exchanger A (including filter and associated service valves)	18
Heat Exchanger A	41
Heat Exchanger B	29
Line From Heat Exchanger B to Fluid-Cooling and Pumping Unit (including service valves and electrolysis unit bypass orifice)	12

The pressure-drop characteristics of the remaining LSS components were not independently determined. However, based upon manufacturer's design data, the resistances of these units were well below those measured for the cabin air heat exchangers. Hence, a significant amount of fixed resistance had to be introduced into the remaining branch circuits (normally by means of balancing valves) to attain the desired flow distribution. The presence of these high-pressure-drop fixed resistances in low-pressure-drop branch circuits were beneficial in that they minimized and frequently almost eliminated flow fluctuations caused by the cyclic operation of equipment.

8.1.3.3 Process-Heat Circuit. The heat-transport fluid (DC-331) selected for use in this circuit performed well and did not demonstrate any undesirable characteristics throughout the entire test program.

Fluid-Heating and Pumping Unit. During the early phases of the test program, it was noted that particulate matter was being generated within the fluid circuit in the fluid-heating and pumping unit. Subsequent tests and inspections indicated that this matter consisted of:

- a. Scale formed on the heating elements.
- b. Metallic particles generated through wear of the fluid pump.
- c. Rust from the unit compressor tank.

The scale formation on the heating elements was tentatively attributed to deterioration of the heater sheathing due to excessive element surface temperature generated under conditions of low fluid-flow rate. This situation was subsequently rectified by:

- a. Readjusting the manual valve in the recirculating-bypass line so as to provide sufficient fluid flow through the heater to prevent large temperature gradients from forming in the heater housing regardless of external fluid-flow rate to the test bed.
- b. Operating the unit at a fluid-discharge pressure below that required to open the pump pressure-relief valve (55 psig). Once this discharge pressure is exceeded, the majority of the flow produced by the pump is short-circuited to the inlet side of the pump, thus essentially starving the heater.

The excessive wear demonstrated by the unit pump was due to cavitation caused by the presence of a high-pressure-drop angle valve immediately upstream of the pump inlet. When this service valve and a similar one located downstream from the pump were removed, the pump demonstrated improved performance and the noise previously generated by its operation was significantly reduced.

The rust present in the compression tank was attributed to prolonged periods of unit operation with the tank vented to atmosphere. This tank was later provided with (1) a stand-pipe to prevent overfilling and (2) a pressure-relief vent. These modifications permitted the unit to be operated with a closed compression tank while preventing excessive pressures from developing in the circuit due to thermal expansion of the heat-transport fluid.

After these modifications were made, the unit was disassembled and cleaned to remove entrapped particulate matter from components that were readily accessible. The unit then performed satisfactorily and released particulate matter in almost negligible amounts -- the gradually decaying magnitude of which indicated it was primarily residual matter not removed during the cleaning operation.

Additional tests performed over a wide range of fluid-inlet temperatures and flow rates indicated that the installed fluid-discharge temperature-control system required a span of $\pm 30^{\circ}\text{F}$ to go from a no-load to a maximum load condition. This control system was subsequently modified to reduce the span to $\pm 3^{\circ}\text{F}$ thus providing a more suitable temperature-control system.

During the final demonstration test (13 July 1965), the unit operated over a range of heat loads from 5.77 kw to 8.85 kw while maintaining a constant fluid-discharge temperature at $400 \pm 2^{\circ}\text{F}$. Throughout this test the unit maintained a flow rate of $300 \pm 10\text{ lb/hr}$ against an external system resistance of $37 \pm 2\text{ psig}$. The maximum unit electrical-energy requirements corresponding to these performance characteristics are listed in Table 8.1-IV.

Table 8.1-IV. Performance Characteristics, Fluid-Heating and Pumping Unit, 13 July 1956

FLUID (DC-331) CIRCUIT				
FLOW RATE (lb/hr)	HEATING LOAD (kw)	DISCHARGE TEMPERATURE (° F)	PRESSURE (psig)	
			DISCHARGE	INLET
300 ± 10	8.85	400 ± 2	49 ± 1	12 ± 1

ELECTRICAL-ENERGY REQUIREMENTS (amps)					
PUMP ONLY			COMPLETE UNIT		
PHASE A	PHASE B	PHASE C	PHASE A	PHASE B	PHASE C
1.0	1.0	1.0	19.0	20.0	1.0

Process-Heat Distribution Circuit. Throughout the test and development program, only one significant change was made to the routing of the fluid lines in this circuit. The feces dryer and wash water heater (connected in series) were originally connected in parallel to the food water heater (in the wash water recovery unit circuit). However, heat losses associated with the long lengths of interconnecting lines from the water recovery units to these units, coupled with the low fluid-flow rates, caused excessive fluid-temperature drops. Hence, the fluid-inlet temperatures to the feces dryer, wash water heater, and food water heater were too low to produce the desired operating characteristics. Therefore, the feces dryer and wash water heater were installed (in series) in a separate branch circuit immediately downstream of the fluid-heating and pumping unit. This change permitted the food water heater to receive the total fluid-flow rate from the water recovery units, which resulted in substantially higher fluid-inlet temperature while simultaneously eliminating a significant length of fluid line.

A simplified schematic of the resulting distribution system is illustrated in Figure 8.1-5. Also shown in this figure is the flow balance used to satisfy the component thermal heating requirements.

During the first phase of the final demonstration test (13 July 1965), this circuit demonstrated a system resistance of 37 psig at a design fluid-flow rate of 300 lb/hr. This pressure drop was significantly higher than during preliminary testing and was attributed to a restriction in the balancing orifice of the feces dryer/wash water heater branch circuit. This restriction was subsequently removed, and during the final phase of the demonstration test (15 July 1965) this circuit demonstrated a pressure drop of only 25.5 psig at the design total-flow rate.

The magnitude of the pressure drops introduced by the individual components were established in earlier tests and are summarized in Table 8.1-V.

The line-pressure drops were insignificant (less than 1 psig) due to the low fluid-flow rates employed in this circuit.

It is readily apparent from the above data that the CO₂ concentration unit introduces the controlling pressure drop into the system. Therefore, a significant amount of fixed resistance (normally in the form of balancing orifices) had to be introduced into the remaining branch circuits to attain the desired flow distribution.

The presence of these high-pressure-drop fixed resistances in low-pressure-drop branch circuits were beneficial in that they minimized and frequently almost eliminated flow fluctuations caused by the cyclic operation of equipment.

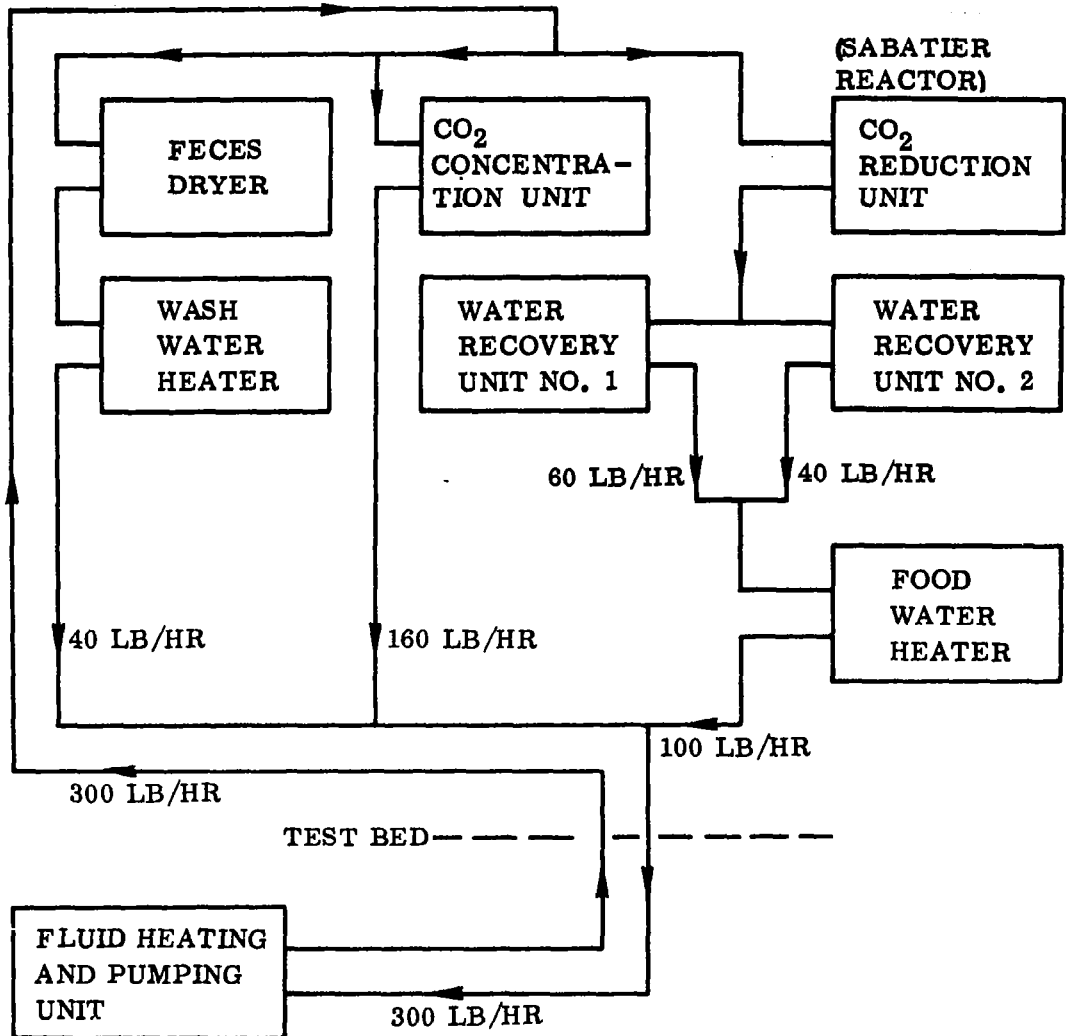


Figure 8.1-5. Process Heat (DC-331) Circuit Flow Distribution

Table 8.1-V. Pressure Drops Introduced by Individual Components

COMPONENT	DC-331 FLOW RATE (lb/hr)	PRESSURE DROP (psig)
<u>Branch Circuit No. 1</u>		
CO ₂ Concentration Unit	160	25.0
<u>Branch Circuit No. 2</u>		
CO ₂ Reduction Unit	100	2.0
Water Recovery Unit No. 1	60	0.5
Water Recovery Unit No. 2	40	0.2
Food Water Heater	100	3.0
<u>Branch Circuit No. 3</u>		
Feces Dryer	40	0.3
Wash Water Heater	40	0.3

8.2 ATMOSPHERIC CONTROL

8.2.1 CO₂ CONCENTRATION UNIT

8.2.1.1 SAI Tests. Testing of the CO₂ concentration unit at the Hamilton Standard Division of United Aircraft, Windsor Locks, Connecticut, was accomplished to demonstrate compliance with Convair Specification 64-02004. This testing was performed in accordance with the acceptance test plan, dated 9 September 1964, as modified by Supplement 1, dated 18 November 1964.

Testing was performed in two phases: (1) separate preliminary tests involving only the zeolite canisters to demonstrate regeneration of a zeolite bed poisoned by excess moisture; (2) system testing at the conditions specified in Paragraph 6.0 of the test plan supplement. The test conditions specified in Paragraph 6.0 are reproduced in Table 8.2-I. Complete details of this phase of testing are contained in HSD CO₂ Concentration Unit Test Report, dated 17 February 1965.

Zeolite Canister Regeneration. A single zeolite canister was tested to demonstrate regeneration of the zeolite bed following poisoning of the bed with water. The correct combination of flow and pressure was obtained by using pressurized dry air. A CO₂ partial pressure was maintained by the introduction of controlled flow of gaseous CO₂ into the test chamber at the canister inlet. Cyclic operation of the system was performed manually. The following test conditions were established.

Table 8.2-I. Provisions of Paragraph 6.0, Acceptance Test Plan, Supplement 1

TEST NO.	INLET AIR TEMPERATURE (° F)	INLET AIR PRESSURE (psia)	INLET CO ₂ PARTIAL PRESSURE (mm Hg ± 0.2 mm)	INLET AIR DEW POINT (° F)	TEST DURATION (hr)	DESORPTION MODE
1	40 (45 maximum)	10 ± 0.5	3.8	34	15	Thermal
2	40 (45 maximum)	10 ± 0.5	7.6	34	3	Thermal
3	55 (59 maximum)	10 ± 0.5	3.8	55	3	Thermal
4	55 (59 maximum)	14 ± 0.5	3.8	55	3	Thermal
5	40 (45 maximum)	10 ± 0.5	3.8	34	3	Vacuum

Inlet pressure	10 psia
Inlet temperature	75 ± 4° F
Inlet P _{CO₂}	3.45 mm Hg
Inlet moisture	less than 50 ppm
Air flow	90 lb/hr
DC-331 flow	160 lb/hr
DC-331 temperature	
Heating	360 ± 10° F
Cooling	75 ± 15° F

The canister-performance characteristic obtained under these conditions is presented in Figure 8.2-1, Curve A. The bed was then contaminated by running 5 cycles with inlet air at a dew point of 30° F being drawn from the test chamber through the zeolite bed. The resultant degeneration of canister performance is presented in Figure 8.2-1, Curve B.

The bed was then regenerated by introducing hot DC-331 into the embedded coils and exposing the air side of the canister to low pressure created by a vacuum pump. Canister pressure was rapidly decreased from 10 psia to 2900 microns and subsequently to 550 microns over a 6.5-hour period. At the end of this time, cyclic operation was resumed at the original conditions. Equilibrium bed performance after 14 cycles is presented in Figure 8.2-1, Curve C. Satisfactory regeneration of the bed was, therefore, demonstrated since Curves A and C are essentially equivalent.

Performance Testing. During preparation for SAI testing it became apparent that CO₂ delivery rate and purity was deficient. Because it appeared that accumulator leakage might be a cause of this deficiency, the accumulator circuit was eliminated from the test setup. The five tests defined by Paragraph 6.0 of the test plan supplement were run to demonstrate the adequacy of the functional operation of the unit. Adsorption rate was obtained from measurement of zeolite bed inlet and outlet CO₂ concentration and air-flow rate but delivery rate was not obtained. Attempts to define CO₂ purity by directing the desorbed gas into a CO₂ analyzer yielded varying results all of which, however, indicated low CO₂ purity.

Following SAI tests, additional testing by HSD was undertaken to determine the delivery rate and cause of low CO₂ purity delivered from the unit. To accomplish this, the desorbing CO₂ was collected in a rubber balloon. The volume of gas collected was established by making several circumferential measurements to establish a nominal diameter of an assumed sphere and calculating the volume of this sphere. Weight

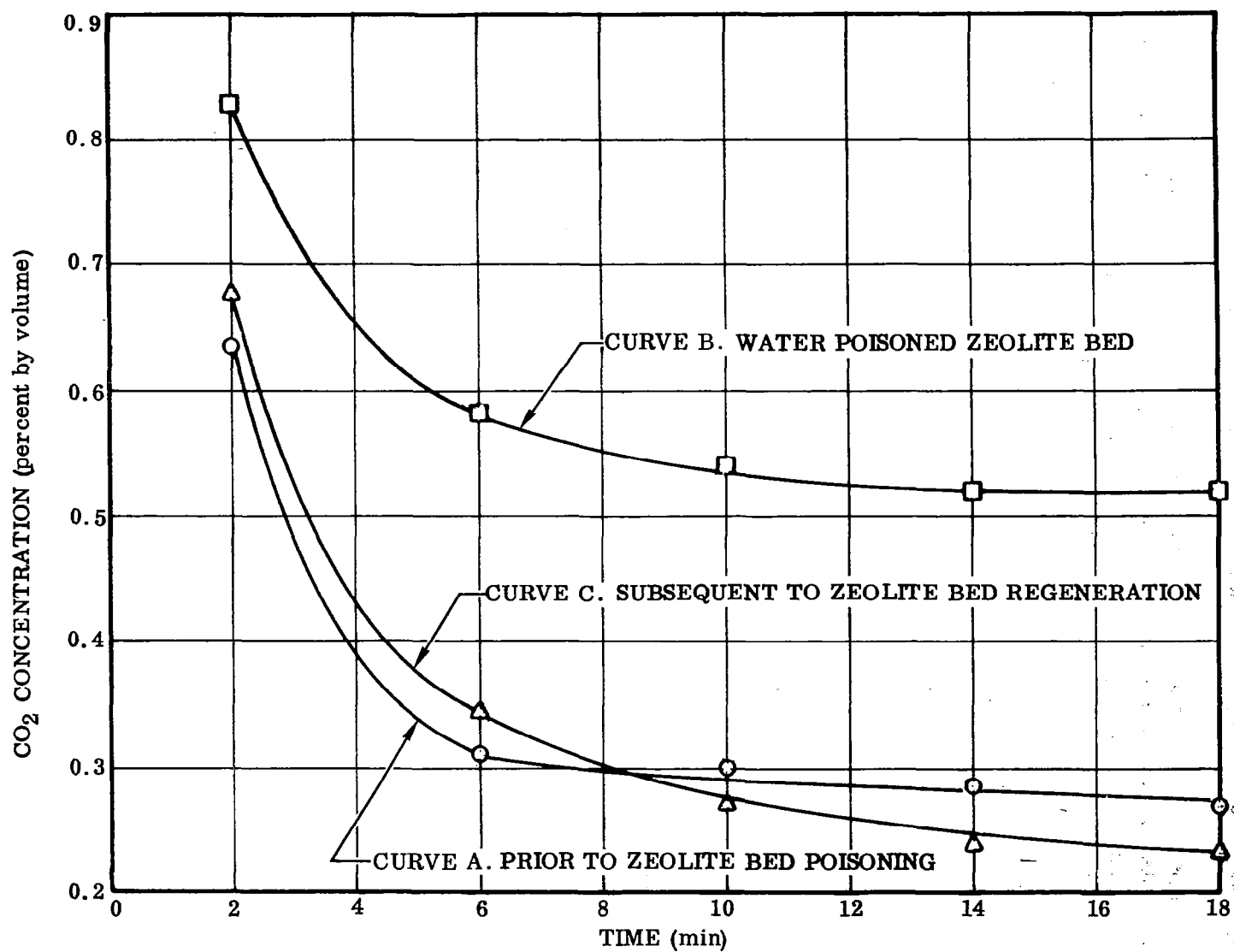


Figure 8.2-1. CO₂ Concentration Unit Preliminary Canister Tests

measurements were then made to check gas quantity from the volume calculated. Gas purity was established by Orsat analysis or by IR analysis.

Unit performance as analyzed from the above measuring techniques was then investigated. As a result of this investigation, the timer was reset to operate the zeolite canisters on a 40-minute cycle (originally 20 minutes) and other minor timing adjustments were incorporated. Further analysis of test data following shipment of the unit to Convair resulted in recommendation by HSD to incorporate further cycle-timing changes to improve system performance. Test results from the SAI tests and post-SAI tests are not included in this section because further system modification resulting in improved performance was obtained at Convair. In addition to the delivery rate and purity problem described above, mechanical problems were also encountered. These problems included:

- a. Lack of diverter-valve override by the high-temperature sensor. All testing was conducted with operation of the diverter valve on command of the timer. This override control was modified following SAI tests. The sensing location was changed from fan outlet to fan inlet.
- b. Fluid valves apparently stuck occasionally causing high circuit-pressure drop. The DC-331 inlet valve, Item 21, was disassembled but showed no evidence of malfunction.
- c. The boost pump/motor coupling slipped several times during the testing. The coupling was replaced and the pump shaft reworked to obtain a positive drive.
- d. The motor shaft for the boost pump was sheared as a result of inadvertent dead heading of the pump. The entire motor was replaced.
- e. Initial attempts to function in the vacuum desorption mode led to discovery of improper operation of the vacuum valve, Item 14, caused by circuit coupling in the control circuits. The malfunction was eliminated by installation of diodes to isolate the circuits.
- f. Difficulties during preparation for the SAI were encountered. The system fan did not operate properly because of a bad bearing, which was replaced and normal operation restored. The intermediate fluid-loop pump malfunctioned because of a crimped wire in the motor, which had been improperly assembled by the manufacturer.
- g. During post-SAI leak check of the system, the vacuum duct connecting Items 10, 13, and 14 was exposed to an internal pressure in excess of 35 psig. This pressure caused the duct to rupture along several welded joints. A new duct was installed.

The unit was accepted for shipment to Convair because the basic function of the unit was adequate and it was anticipated that improved performance could be obtained during subsequent testing at Convair.

8.2.1.2 Convair Functional Checkout. Upon receipt of the unit in the Convair Life Sciences Laboratory, the unit was visually inspected for shipment or other damage that might require work on the unit prior to installation within the LSS test bed. The system was then installed in the test bed and system interfaces connected. A functional-checkout procedure was prepared and approved. Checkout of the unit was initiated on 12 January 1965 and completed by 1 February 1965.

Problems encountered during this functional checkout were:

- a. The press-to-test light for ac-power indication was found to be a 28-vdc type. This light was replaced with a neon light with proper receptacle and verified to function properly.
- b. The thermal-desorption-mode light was found to be burned out and was replaced.
- c. The fan ΔP gauge was incorrectly connected to the fan pressure ports. The flex lines inside the control panel were reversed and the gauge then recorded correctly.
- d. The timer motor was declutched from the cam train and the cam train manually rotated from the front of the panel. Only the forward three cams rotated by this method and the timing sequence was thus misadjusted. The system was run in auto mode with the fan off and timing of the forward cams readjusted to that of the other cams. Manual rotation of the cam train by means of the knob provided on this unit is, therefore, not permissible.
- e. Thermocouple temperatures were observed during operation. Some of the thermocouples were apparently either erroneous or mislabeled as to location.
- f. During operation of the silica gel valve actuator, the insulation interfered with rotation of the knurled knob provided on the actuator for manual override. This knob was removed and reduced in diameter by approximately 1/2-inch and reinstalled.

As a further part of the functional checkout, the vacuum valve, Item 14, was electrically isolated from the system and driven to the closed position. The vacuum system from the valve to the main vacuum pump was then evacuated. The system pumped to a pressure of about 60 microns in 10 minutes. A final pressure of 17-20 microns was achieved after about 3 hours.

The electrolytic hygrometer, pump, and alarm relay were incorporated into the system. The electrolytic-sensor element was dried using dry nitrogen. The system was then put into the dry-down mode according to HSD preliminary operating instructions. The beds took approximately 4 hours drying time (total) to achieve a water concentration of less than 100 ppm from the silica gel beds. The system was then put into auto mode to check cycle timing. Adequate observation of sequenced operations was not possible with the instrumentation provided on the unit. A separate status panel consisting of timing lights showing each sequenced operation was fabricated and installed. The timing sequence recorded by HSD was then verified.

A calibrated-orifice section and gauge was installed at the inlet to the unit and the fan calibrated in place on the unit. A calibration curve slightly different from that supplied by HSD was obtained. Since HSD calibrated the fan as an isolated unit, it was felt that the difference was probably due to the fan being calibrated installed rather than separately.

With resolution of the foregoing problems and observation of unit operation, it was verified that the unit was correctly installed and functioning normally. Testing could, therefore, be initiated to define unit performance and to evaluate CO₂ concentration capability in the test-bed installation.

8.2.1.3 Unit Evaluation. During unit evaluation at Convair, an operational time of slightly more than 67 hours, exclusive of dry-down time, was accumulated on the unit. During this period many modifications were made to the unit to improve the performance and operational characteristics of the system.

A test-run summary is presented in Table 8.2-II. The period between the end of functional checkout and the NASA witnessed test of 8 April 1965 was devoted primarily to incorporating such fixes and modifications as found necessary to adequately provide a functionally sound unit with sufficient instrumentation to observe performance. The major problems encountered during this period consisted of: (1) detection and elimination of air leakage into the desorbing CO₂, (2) timing the system to HSD recommendations, which required installation of timing lights to permit observation of cyclic functions, (3) detecting and changing thermocouples, which were either defective or incorrectly installed, and (4) determination of CO₂ accumulator and zeolite canister void volume by gas flow methods, (zeolite canister void volume could not be determined).

Other minor problems such as leakage of the heating and cooling fluids and some instances of valve malfunctions were encountered as would be anticipated in a program of this nature.

Air Leakage. Leakage in the unit was detected in several locations. A leak in a weld in the vacuum duct connecting the zeolite valves to the space vacuum valve was detected and eliminated by rewelding. Conoseals were replaced at zeolite valve, Item 13, at the 4-inch capped duct at the Item-13 end of both zeolite canisters, and at the joints of the vacuum duct.

Item 17, the CO₂ diverter valve, was found to be leaking CO₂ back to the purge line when the valve was in the divert-to-accumulator mode. This valve was disassembled and the solenoid actuated plunger found to have become misadjusted. The plunger was readjusted and the valve modified to provide locking of the adjustment so that future inadvertent change in the adjustment would be eliminated.

The leakage of the system may be noted through observation of the canister-pressure history during unit operation. Figures 8.2-2 and 8.2-3 illustrate this effect.

Table 8.2-II. CO₂ Concentration Unit Time Summary

RUN DATE	TEST BED PRESSURE	DESORB MODE	TEST OBJECTIVE	RUN TIME START/STOP	REMARKS
1. 11 Feb.	S.L.	Thermal	Performance check as received	1028/1140	
2. 17 Feb.	S.L.	Thermal	1) Performance rate adsorb 2) Accumulator pressure history 3) Temperature history 4) Fan calibration	0908/1350	Item 17 leaking
3. 23 Feb.	S.L.	Thermal	Repeat of run of 17 February	1731/1929	Item 17 repaired
4. 1 March	S.L.	Thermal	Canister pressure accumulator pressure Adsorb rate	132/1600	
5. 18 March	S.L.	Vacuum		1729/1852	
6. 26 March	S.L.	Thermal		1401/1740	
7. 30 March	10 psia	Thermal	Initial system integration (not O ₂)	1824/2114	
8. 8 April	10 psia	Vacuum	NASA demonstration	1021 = 17 hours	Item 21 leaking
9. 11 May	S.L.	Thermal	Inlet concentration in purge	1620/1733	CO ₂ at inlet to No. 17 through purge.
10. 20 May	10 psia	Thermal	Performance check	1508/1822	Deleted No. 14 rotation in thermal mode 14 May 1965. Pump always on.
11. 4 June	S.L.	Thermal	Performance check	1523/1635	
12. 9 June	S.L.	Thermal	Performance check	1509/1639	
13. 10 June	S.L.	Thermal	Rerun of 4 June	1400/1625	Rerun of 4 June. Check gas analysis.
14. 10 June	10 psia		Rerun of 20 May	1740/2015	Rerun of 20 May.
15. 18 June	19 psia	Vacuum	Performance check	1918/2145	
16. 24 June	S.L.	Thermal	Purity (CO ₂) check	1313/1704 1108 = 18.5 hours	
17. 25 June	S.L.	Thermal	Purity check	1636/1916	Purge time 18 minutes.
18. 26 June	S.L.	Thermal	Purity check	1216/1632	Purge time 18 minutes.
19. 26 June	10 psia	Thermal	Integrated test	1653/1930	Purge time 18 minutes. Purge line reconnected to inlet.
20. 28 June	S.L.	Thermal	Purity check	1334/1654	Purge time 13.5 minutes.
21. 29 June	S.L.	Thermal	Purity check	1044/1203	Purge time 13.0 minutes.
22. 29 June	S.L.	Thermal	Purity check	1418/1618	Purge time 13.0 minutes.
23. 1 July	S.L.	Thermal	Purity check	1119/1150	Purge time 12 minutes.
24. 1 July	S.L.	Thermal	Purity check	1355/1635	Purge time 12 minutes.
25. 2 July	S.L.	Thermal	Purity check	1524/1650	Purge time 9.5 minutes.
26. 6 July	S.L.	Thermal	Purity check	1439/1713	Purge time 10.5 minutes.
27. 9 July	S.L.	Thermal	Purity check	1341/1622	Purge time 11 minutes.
28. 13 July	10 psia	Thermal	NASA demonstration	1400/1744	
29. 15 July	10 psia	Vacuum	NASA demonstration	1235/1440 1913 = 32 hours = 67.3 hours	

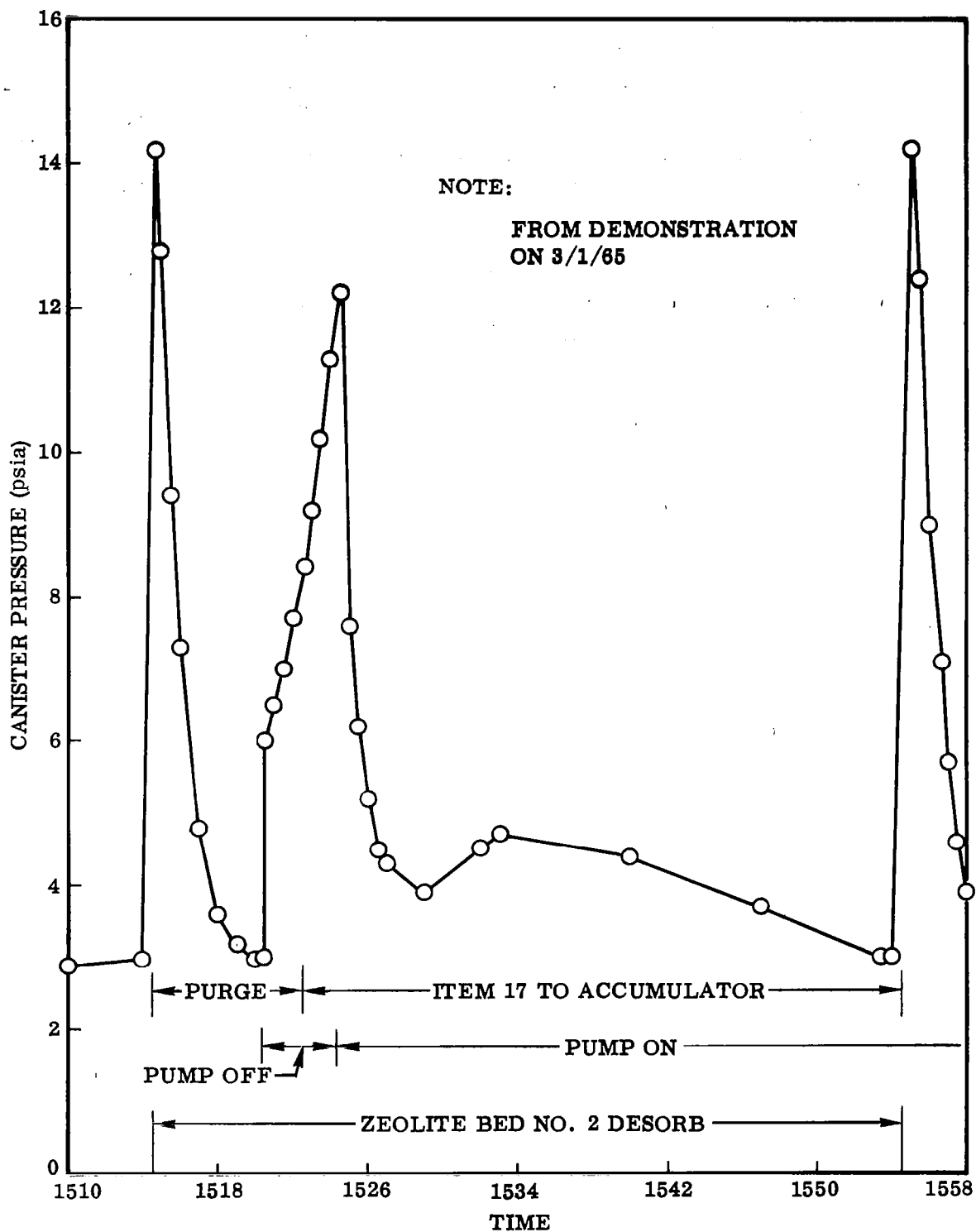


Figure 8.2-2. CO₂ Concentration Unit Canister Pressure History (1 March 1965)

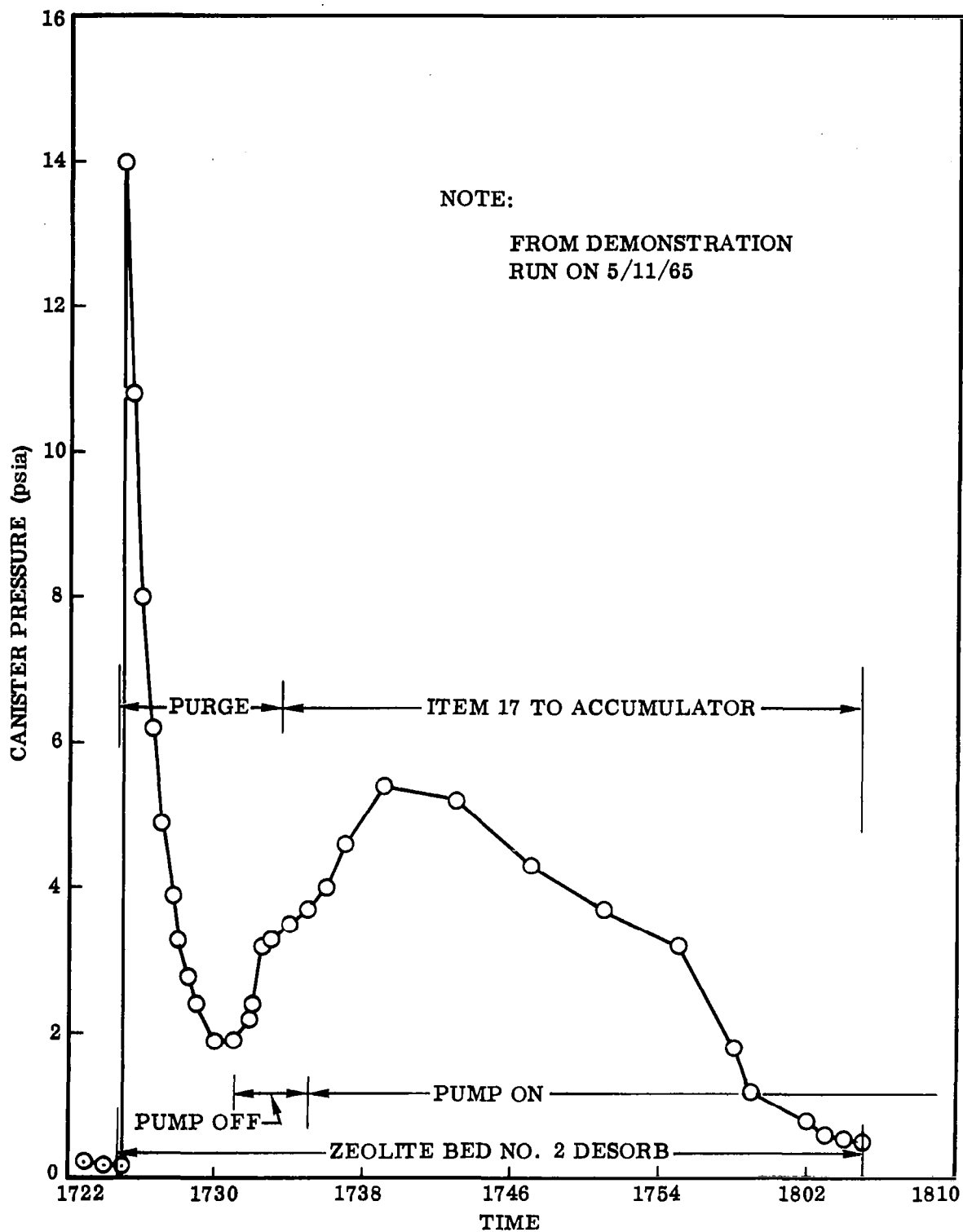


Figure 8.2-3. CO₂ Concentration Unit Canister Pressure History (11 May 1965)

Leakage was present during the run of 1 March 1965, shown in Figure 8.2-2, and had been essentially eliminated by the time the run of 11 May 1965 (Figure 8.2-3) was made. Air leaking into the canister desorbing system causes a large increase in canister pressure when the pump is turned off. A small increase in pressure, as shown in Figure 8.2-3 is the result of hot fluid being diverted to the canister and causing CO_2 to be evolved from the bed but not being pumped away. It may also be observed that initially the pump could only pull the canister pressure to about 3.0 psia when leakage was present. After fixing the leaks, the canister pressure could be decreased to 0.5 psia or less with this same pump.

Cycle Timing. During post-SAI testing at Hamilton Standard Division, the zeolite canister cycle time was changed from 20 minutes to 40 minutes and other minor changes were also made. The changes were made only on the thermal mode as time did not allow HSD to incorporate the necessary changes in the vacuum mode. This was accomplished at Convair. In addition to these changes, subsequent analysis of test data by HSD resulted in their recommending other changes in cycle times to improve system performance. As initially delivered, the information display provided with the unit was not adequate to permit accurate determination of the unit cyclic functions. A set of timing lights was fabricated and installed so that cyclic operation could be observed. This technique was eventually incorporated as a permanent part of the unit in the form of a back-lighted schematic that depicted valve sequencing as well as timing.

The unit was timed using the lights, and cycle times slightly different from those presented by HSD were obtained. Runs were made with this timing, and then the unit was retimed in accordance with the latest HSD recommendations. Figures 8.2-4 through 8.2-6 represent the evolution of the unit-timing sequences during this phase of development testing. The final unit-timing sequence as determined from advanced testing at Convair is shown in Figure 8.2-7. This was the timing in the unit as shipped to NASA/LRC.

Accumulator and Zeolite-Canister Void Volume. Information was supplied by HSD regarding void volume of the CO_2 accumulator and also the zeolite canister and ducting in their final test report dated 17 February 1965. The accumulator volume was given as 2.21 ft^3 , which was a calculated value based on accumulator geometry. A volume ratio of 2.67 was used to define pressure changes based on calculated volumes that would thus yield a void volume of 0.828 ft^3 for the zeolite canister and ducting system. This latter value was apparently in error since by consideration of system geometry, excluding volume occupied by zeolite, cooling coils, etc. located within the canisters and ducting, a maximum value of approximately 0.75 ft^3 is obtained. Because of this discrepancy and the desire to verify the reported value for accumulator volume, tests were made to experimentally determine these volumes. The test method used was pressurization of the test volume for a timed period. Knowledge of the pressure change, time, total gas quantity delivered, and gas characteristics then yields an experimental value for the volume being considered. The analytical method used for this determination was:

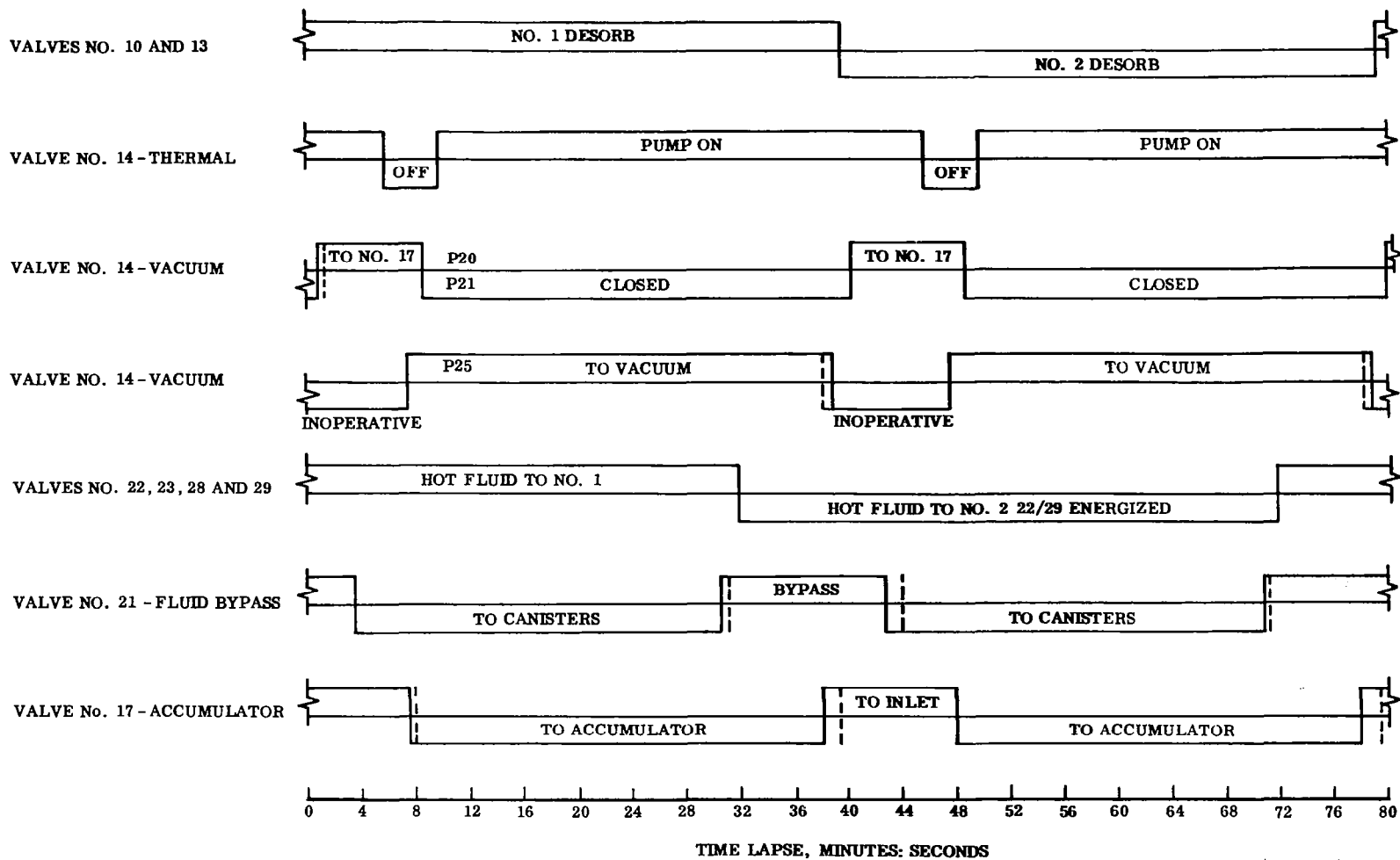
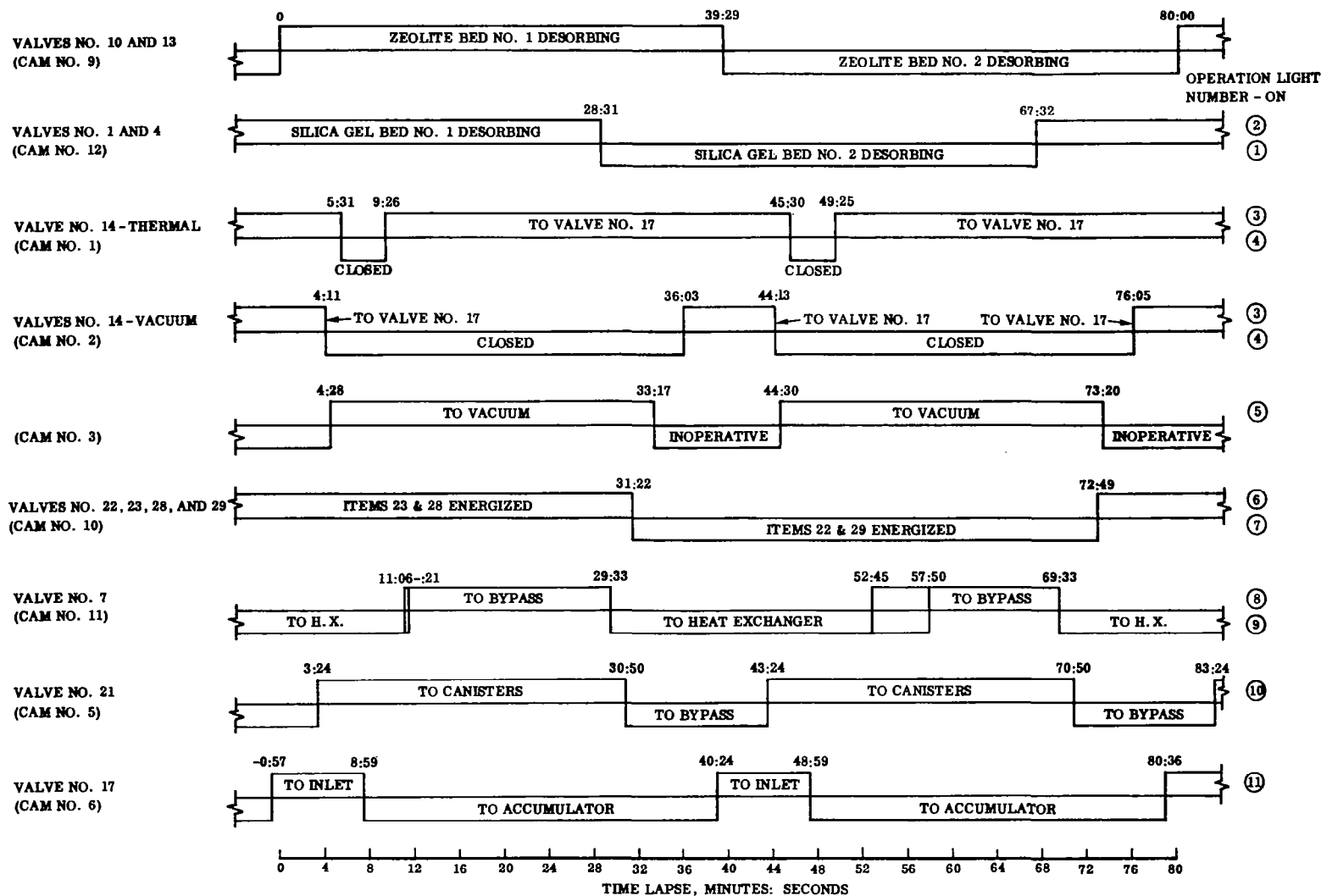


Figure 8.2-4. CO₂ Concentration Unit Repeat Cycle Sequence

Figure 8.2-5. CO₂ Concentration Unit Timer Sequence as Received at Convair

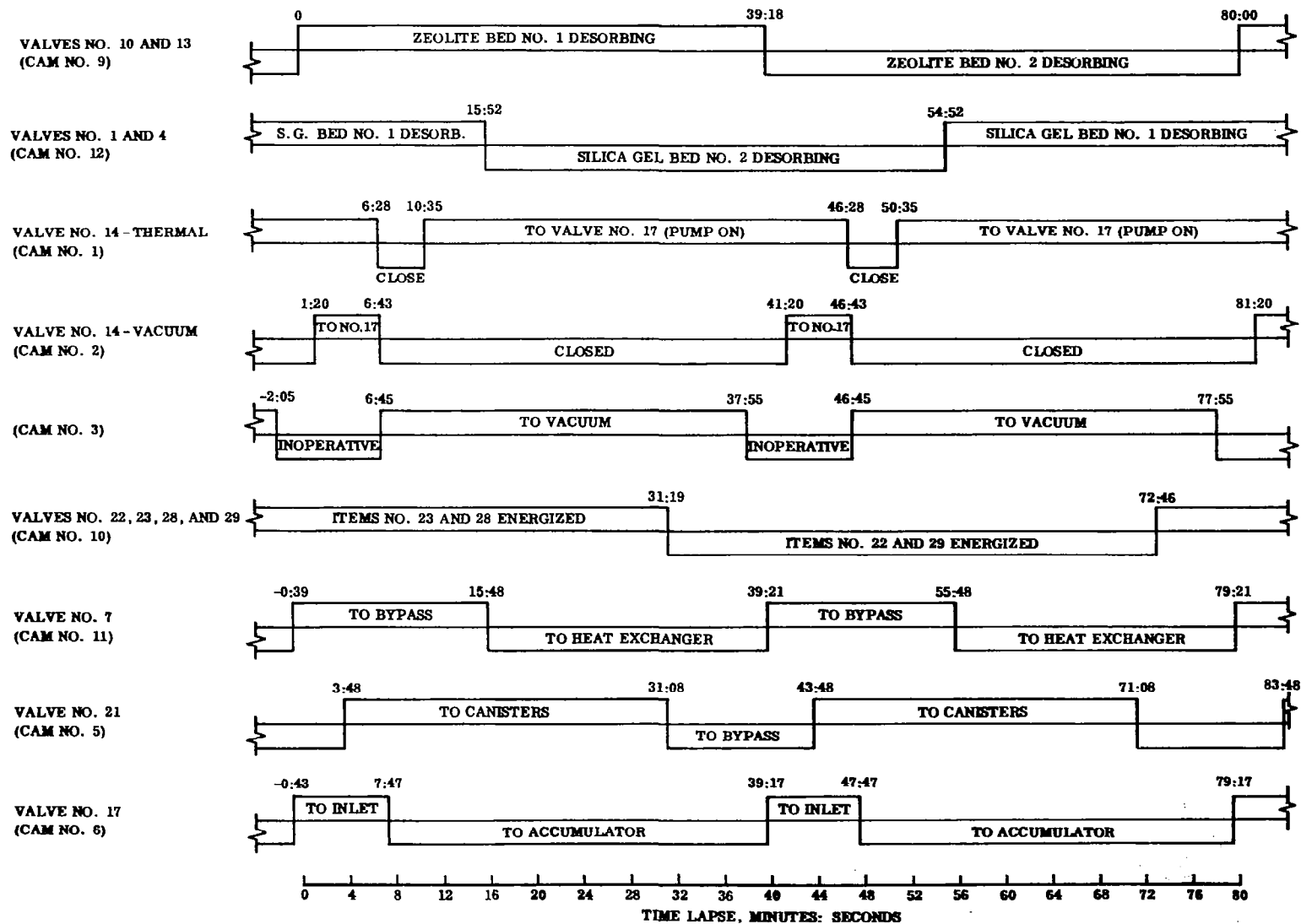
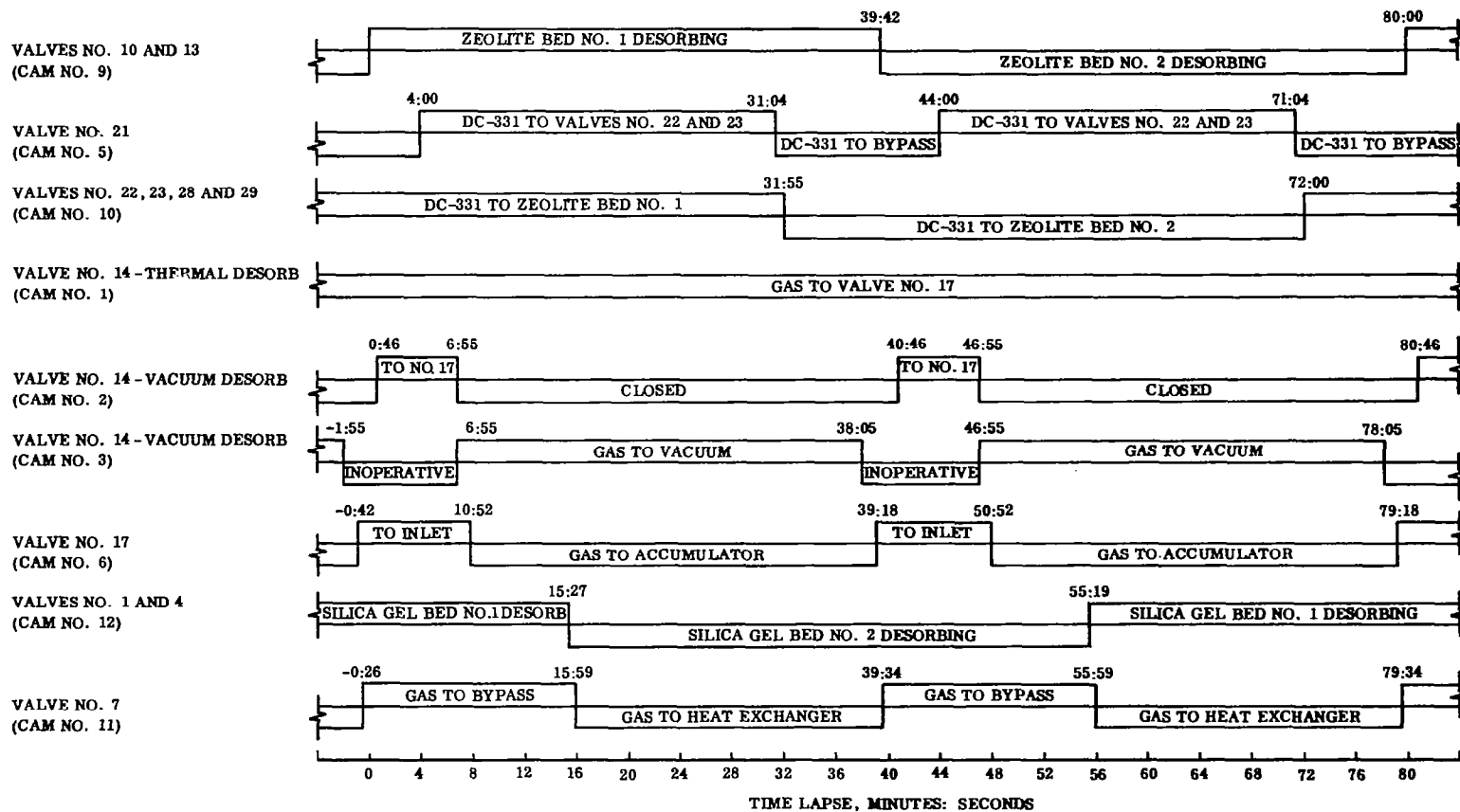


Figure 8.2-6. CO₂ Concentration Unit Preliminary Timer Sequence

Figure 8.2-7. CO₂ Concentration Unit Final Timer Sequence

$$\text{Using } PV = \frac{WRT}{144 M}$$

P = pressure, psia

V = volume, ft³

W = weight of gas, lb

R = universal gas constant, 1545

T = temperature, °R

M = molecular weight of gas being used

and differentiating with respect to time (assuming constant temperature)

$$\frac{dP}{dt} = \frac{dW/dt \cdot RT}{144 MV}$$

Using a constant rotometer reading to determine gas flow and standard temperature

$$\frac{dW}{dt} = K \sqrt{P/14.7}$$

where K = flow rate of pressurizing gas under standard conditions

$$\text{and } \frac{dP}{dt} = K \sqrt{\frac{P}{14.7}} \left(\frac{RT}{144 MV} \right)$$

$$\frac{dP}{P^{\frac{1}{2}}} = \frac{K_1 T dt}{MV}$$

$$K_1 = \frac{1545 K}{144 \sqrt{14.7}} = 2.80 K$$

$$\int_{P_1}^{P_2} (P)^{-\frac{1}{2}} dP = \int_0^t \frac{2.80 KT}{MV} dt$$

$$2 \left[(P_2)^{\frac{1}{2}} - (P_1)^{\frac{1}{2}} \right] = \frac{2.80 KT}{MV} (t)$$

or

$$V = \frac{1.40 KT}{\left[(P_2)^{\frac{1}{2}} - (P_1)^{\frac{1}{2}} \right] M} \quad (t)$$

and letting $T = 535^\circ R$

$$V = \frac{749 K}{M \left[(P_2)^{\frac{1}{2}} - (P_1)^{\frac{1}{2}} \right]} \quad (t)$$

The rotometer used for these tests was Brooks Model No. 4-1110-6, Serial Number 6307-52511, which had been calibrated by the Convair Standards Laboratory for standard air conditions. The calibration curve for this rotometer is presented in the Appendix. A rotometer scale reading of 80 was used to check accumulator volume. This corresponds to a flow of 0.00770 lb/min standard air. The accumulator volume was determined a second time using CO_2 as a pressurizing gas and a Fischer and Porter flowmeter No. 2F 1/4-20-5/36 with float CD 14, which was calibrated in the Life Sciences Laboratory using CO_2 as the calibrating gas. Since the calibrating gas and pressurizing gas were different for the first tests, a correction to determine actual flow was made as follows:

$$\dot{W}_x = \dot{W}_{air} \sqrt{\frac{P_x}{P_{air}} \frac{M_x}{M_{air}} \frac{T_{air}}{T_x}}$$

where x signifies the actual pressurizing gas.

Two runs using N_2 as a pressurizing gas and one run using CO_2 were made to determine accumulator volume. Data obtained from these runs are presented in Table 8.2-III. Experimentally determined volume was 1.93 ft³, 1.96 ft³, and 1.95 ft³ respectively. Subsequent calculations will thus be based on a nominal accumulator volume of 1.95 ft³.

The attempts to determine canister and duct volume were not successful. As previously discussed, the maximum void volume of one canister and the vacuum duct is approximately 0.75 ft³. This does not account for volume occupied by the zeolite, cooling coils, and other elements of the system. If it is assumed that the void volume is about 60 percent of the total volume, then void volume should be approximately 0.45 ft³.

Both canisters were checked for volume using both N_2 and O_2 as pressurizing gases. Data from these tests are presented in Table 8.2-IV. As can be seen from the data, tests were initially run at pressures above atmospheric. Using N_2 as a pressurizing gas, each canister was checked. The first canister was pressurized

Table 8.2-III. CO₂ Concentration Unit Accumulator Volume Check

RUN DATE	POINT NO.	TIME	ROTO METER READING	ACCUMULATOR PRESSURE (psia)	PRESSURI- ZING GAS	REMARKS
3/4/65	1	1637:30	80	15.0	N ₂	Flowmeter was Brooks Model 4-1110-6, S/N 6307-52511.
	2	1638	↓	15.4		
	3	1639	↓	16.2		
	4	1640	↓	17.1		
	5	1641	↓	17.9		
	6	1642	↓	18.8		
	7	1643	↓	19.6		
	8	1644	↓	20.4		
	9	1645	↓	21.3		
	10	1646	↓	22.3		
	11	1647	↓	23.5		
	12	1648	↓	24.5		
3/10/65	1	1631	80	15.3	N ₂	Flowmeter was Brooks Model 4-1110-6, S/N 6307-52511.
	2	1632	↓	16.2		
	3	1633	↓	17.0		
	4	1634	↓	17.9		
	5	1635	↓	18.6		
	6	1636	↓	19.5		
	7	1637	↓	20.4		
	8	1638	↓	21.3		
	9	1639	↓	22.3		
	10	1640	↓	23.4		
	11	1641	↓	24.4		
	12	1642	↓	25.4		
	13	1643	↓	26.5		
	14	1644	↓	27.5		
	15	1645	↓	28.6		
	16	1646	↓	29.8		
	17	1647	↓	30.8		
	18	1648	↓	31.4		
	19	1649	↓	32.0		
	20	1650	↓	32.9		

Table 8.2-III. CO₂ Concentration Unit Accumulator Volume Check, Contd

RUN DATE	POINT NO.	TIME	ROTO METER READING	ACCUMULATOR PRESSURE (psia)	PRESSURIZING GAS	REMARKS
7/8/65	1	0	4.0	14.7	CO ₂	Flowmeter used was Fischer and Porter 2F 1/4-20-5/36, Float CD-14.
	2	2	4.0	15.1		
	3	4	3.8	15.6		
	4	6	4.4	16.1		
	5	8	4.0	16.8		
	6	10	4.1	17.2		
	7	12	4.5	17.8		
	8	14	4.0	18.4		
	9	16	3.9	19.0		
	10	18	4.3	19.7		
	11	20	3.9	20.2		
	12	22	5.0	20.8		
	13	24	4.1	21.6		
	14	26	4.7	22.2		
	15	28	4.7	23.0		
	16	30	4.3	23.8		
	17	32	3.7	24.5		
	18	34	4.7	25.2		
	19	36	4.1	25.9		
	20	38	4.0	26.7		
	21	40	4.0	27.3		
	22	42	3.8	28.0		
	23	44	4.1	28.9		
	24	46	4.6	29.6		

through a pressure range of 14.7 psia to 25.3 psia. Examination of the data indicates three different rates of pressurization resulting in successively smaller calculated volume for each subsequent rate. Considering only the initial portion of the pressurization time, a canister void volume of 1.58 ft³ was obtained. The void volume obtained through test of the second canister was 1.94 ft³. Because this was an impossibly large volume, these tests were rerun using O₂ as a pressurizing gas to check the possibility of N₂ adsorption in the previous tests. From adsorption isotherms of these gases on this zeolite, O₂ should be adsorbed to a lesser extent than N₂ although adsorption of either gas should have been negligible. Void volumes obtained using O₂ were 2.16 ft³ and 2.26 ft³ for each canister respectively. These values essentially confirm those obtained using N₂. To cover the possibility that this phenomenon was due to adsorption of gases at relatively high pressure, tests were run at reduced pressure. The canisters were evacuated to less than 1.0 psia and pressurized with O₂. One

Table 8.2-IV. CO₂ Concentration Unit Zeolite Canister Volume Check*

RUN DATE	POINT NO.	TIME	ROTO METER READING	CANISTER PRESSURE	PRESSURIZING GAS	ZEOLITE VALVE POSITION (deg)
3/11/65	1	1102	40	15.7	N ₂	0
	2	1103		16.0		
	3	1104		16.6		
	4	1105		17.0		
	5	1106		17.5		
	6	1107		17.9		
	7	1108		18.3		<u>V=1.58</u>
	8	1109		18.8		
	9	1110		19.3		
	10	1111		19.8		
	11	1112		20.3		
	12	1113		20.7		
	13	1114		21.3		
	14	1115		21.8		
	15	1116		22.3		<u>V=1.49</u>
	16	1117		22.9		
	17	1118		23.5		
	18	1119		24.1		
	19	1120		24.7		
	20	1121	↓	25.3		↓ <u>V=1.40</u>
3/17/65	1	1741	40	16.3	N ₂	90
	2	1742		16.7		
	3	1743		17.0		
	4	1744		17.4		
	5	1745		17.7		
	6	1746		18.1		
	7	1747	↓	18.5		↓ <u>V=1.94</u>

*Rotometer used for all tests was
Brooks Model 4-1110-6,
S/N 6307 - 52511.

Table 8.2-IV. CO₂ Concentration Unit Zeolite Canister Volume Check, Contd

RUN DATE	POINT NO.	TIME	ROTO METER READING	CANISTER PRESSURE	PRESSURIZING GAS	ZEOLITE VALVE POSITION (deg)
4/21/65	1	1318	40	14.9	O ₂	90
	2	1319	↓	15.2	↓	↓
	3	1320	↓	15.4	↓	↓
	4	1321	↓	15.7	↓	↓
	5	1322	↓	16.0	↓	↓
	6	1323	↓	16.3	↓	↓
	7	1324	↓	16.6	↓	↓
	8	1325	↓	16.9	↓	↓
	9	1326	↓	17.2	↓	↓
	10	1327	↓	17.5	↓	↓
	11	1328	↓	17.7	↓	↓
	12	1329	↓	18.1	↓	↓
	13	1330	↓	18.4	↓	↓ <u>V=2.16</u>
	1	1412	40	14.8	O ₂	0
	2	1413	↓	15.0	↓	↓
	3	1414	↓	15.3	↓	↓
	4	1415	↓	15.6	↓	↓
	5	1416	↓	15.8	↓	↓
	6	1417	↓	16.1	↓	↓
	7	1418	↓	16.4	↓	↓
	8	1419	↓	16.7	↓	↓
	9	1420	↓	17.0	↓	↓
	10	1421	↓	17.3	↓	↓
	11	1422	↓	17.6	↓	↓
	12	1423	↓	17.8	↓	↓
	13	1424	↓	18.2	↓	↓ <u>V=2.26</u>

Table 8.2-IV. CO₂ Concentration Unit Zeolite Canister Volume Check, Contd

RUN DATE	POINT NO.	TIME	ROTO METER READING	CANISTER PRESSURE	PRESSURIZING GAS	ZEOLITE VALVE POSITION (deg)
4/22/65	1	1120	80	0.60	O ₂	0
	2	1123	↓	1.40		↓
	3	1124		1.70		
	4	1125		2.10		
	5	1126		2.55		
	6	1127		3.00		
	7	1128		3.55		
	8	1129		4.10		
	9	1130		4.80		
						<u>V=1.31</u>
	1	1318	40	5.15	O ₂	0
	2	1319	↓	5.40		↓
	3	1320		5.70		
	4	1321		6.00		
	5	1322		6.20		
	6	1323		6.50		
	7	1324		6.80		
	8	1325		7.10		
						<u>V=1.36</u>

test was run holding a rotometer reading of 80 and a second test accomplished holding a rotometer reading of 40 as in the previous tests. The test run using the 80 rotometer reading yielded nonlinear results, whereas all other previous tests produced a linear relationship for canister pressure increase with time. Canister void volumes of 1.31 ft³ and 1.36 ft³ respectively were obtained. This would appear to indicate the effect of pressure as a contributing factor to the observed results.

Sea-Level Thermal-Desorption Performance. Typical unit operational characteristics under sea-level conditions are described by the run of 9 July 1965. Data from this run are included in Tables 8.2-V and 8.2-VI. A part of this information is displayed graphically in Figures 8.2-8 through 8.2-11. System temperatures were not recorded for this run but were monitored from the panel-mounted pyrometer. Flowmeters were added to the system instrumentation to measure the gas flow directly from the CO₂ transfer pump. Figure 8.2-8 shows the CO₂ concentration before and after the adsorbing zeolite bed. Figure 8.2-9 shows the air flow through the system. Using integrated values from these two figures, the CO₂ adsorption rate may be obtained. Selecting the

Table 8.2-V. CO₂ Concentration Unit Sea Level Test Data

TIME (minutes)	AIRFLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{accum} (psia)	H ₂ O ⁽²⁾ (ppm)	DC-331 T _{in} (° F)	DC-331 FLOW ⁽³⁾ ΔP (in. H ₂ O)	GLYCOL FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	SYSTEM A T _{hx-out} (° F)	LABORATORY AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)	LIVING AIR FLOW ⁽⁶⁾ ΔP (in. H ₂ O)	T _{lab} (° F)	T _{living} (° F)	P _{cabin} (mm Hg)	FLOWMETER 2F READING	P _{can} (psi)
1341	Started CO ₂ concentration unit; zeolite bed No. 2 and S. G. No. 2 now desorbing.													
1342	0.62	22.2	31	380	20.2	10.0	~32	0.31	0.34	71	70	752	>20	5.50
1344	0.67	22.2	28	380	20.0	10.8	~32						8.3	1.50
1346	0.69	22.2	33	380	19.2	10.8	~32						3.4	1.10
1348	0.72	22.2	39	379	18.6	10.8	~32						6.4	1.40
1350	0.71	22.2	41	378	20.8	10.8	~32						>20	3.5
1352	0.74	22.2	41	378	-	-							18.1	2.7
1352:27	No. 17 to accumulator													
1354	0.76	23.2	41	379	22.2	10.8	~32						14.3	2.90
1356	0.76	24.3	41	379	21.6	10.8	~32						14.1	2.90
1358	0.79	25.3	42	379	22.1	10.6	~32	0.31	0.33	71	70		12.6	2.80
1400	0.74	26.2	65	379	22.4	10.5	~32						10.6	2.60
1402	0.70	26.9	76	379	22.3	10.6	~32						8.8	2.40
1404	0.69	27.3	80	380	22.3	10.6	~32						7.4	2.20
1406	0.67	27.6	86	380	22.3	10.6	~32						6.3	2.05
1408	0.66	27.9	102	379	22.3	10.6	~32						5.5	1.95
1410	0.65	28.2	102	379	22.2	10.6	~32						4.7	1.85
1412	0.63	28.3	102	379	22.2	10.6	~32	0.31	0.33	72	70		4.1	1.75
1414	0.62	28.3	100	379	21.8	10.8							2.2	1.50
1416	0.59	28.2	100	379	21.8	9.6							1.2	0.50
1418	0.57	28.2	98	379	21.8	10.0							1.0	0.30
1420	0.56	28.2	93	379									0	0.25
1420:53	No. 17 to inlet													
1421:28	Switched zeolite beds; zeolite bed No. 1 now desorbing.													
1422	0.50	28.2	93	379	20.6	9.6							>20	12.3
1422:30 - 1423:30	Took CO ₂ accumulator purity sample.													
1424	0.59	27.2	92	379	21.0	8.9							>20	4.5
1426	0.62	27.2	88	379	9.5	8.8							11.8	2.40
1426:30 } 1427:30 }	Took CO ₂ accumulator purity and bleed down accumulator.													
1428	0.64	18.6	90	376	-	-							11.0	2.40
1430	0.64	18.6	91	376	17.0	10.0							15.2	3.00
1432	0.64	18.6	92	377	-	-							15.9	3.15
1432:28	No. 17 to accumulator													
1434	0.64	20.0	94	377	15.2	10.8							>20	3.75
1436	0.61	22.1	95	377	16.9	10.8	~32	0.32	0.33	72	71	752	>20	4.45
1438	0.68	24.8	85	377	16.2	10.8							>20	4.60

(1) Orifice calibration of 5/19/65

(4) Orifice K105-F

(2) @ 95 cc/min and 1 psi

(5) Orifice A108-F

(3) Orifice H104-F

(6) Orifice A109-F

Table 8.2-V. CO₂ Concentration Unit Sea Level Test Data, Contd

TIME (minutes)	AIRFLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{accum} (psia)	H ₂ O ⁽²⁾ (ppm)	DC-331 T _{in} (° F)	DC-331 FLOW ⁽³⁾ ΔP (in. H ₂ O)	GLYCOL FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	SYSTEM A T _{hx-out} (° F)	LABORATORY AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)	LIVING AIR FLOW ⁽⁶⁾ ΔP (in. H ₂ O)	T _{lab} (° F)	T _{living} (° F)	P _{cabin} (mm Hg)	FLOWMETER 2F READING	P _{can} (psi)
1440	0.71	28.1	63	377	15.9	10.8							>20	4.35
1442	0.73	29.1	60	377	15.9	10.8							18.0	3.9
1444	0.74	30.5	57	377	16.1	10.7							15.3	3.55
1446	0.75	31.8	56	377	23.2	10.8							12.0	—
1448	0.75	32.7	55	378	22.7	10.8							10.3	3.05
1450	0.73	33.3	54	385	22.5	10.8	~32	0.32	0.33	72	70.5		8.6	2.85
1450:30 } 1451:00 }	Added CO ₂ to cabin.													
1452	0.71	34.0	52	386	22.0	10.8							7.4	2.65
1454	0.69	34.4	49	386	29.0	10.8							4.9	2.15
1456	0.67	34.3	47	387	27.5	10.6							0	0.80
1458	0.62	34.2	45	387	28.8	11.0							0	0.30
1500	0.56	33.9	44										0	0.25
1501:17	Switched zeolite beds; zeolite bed No. 2 now desorbing.													
1502	0.40	33.8	43	387									>20	8.8
1502:30 } 1503:30 }	Took CO ₂ accumulator purity sample.													
1504	0.43	33.0	42	387	29.6	9.5							18.6	3.9
1504:30 } 1505:30 }	Took CO ₂ accumulator purity.													
1506	0.43	31.2	41	387	17.8	9.2							11.5	2.45
1508	0.42	31.3	40	387	28.5	9.6							15.9	3.25
1508:30 } 1509:30 }	Took CO ₂ accumulator purity sample; bleeding down accumulator.													
1510	0.41	20.6	40	386	>30	10.5							18.0	3.50
1512	0.41	20.8	39	384	>30	11.2							17.8	3.40
1512:26	No. 17 to accumulator													
1514	0.41	22.3	39	381	21.0	11.2							>20	3.75
1516	0.43	24.3	38	382	20.8	11.2							>20	3.75
1518	0.48	26.1	38	382	22.0	11.2	~32	0.33	0.34	72	71		17.8	3.60
1520	0.56	27.5	39	382	—	—							15.3	3.35
1522	0.59	28.8	39	382	21.5	11.2							12.5	3.05
1524	0.61	29.8	39	382	21.6	11.2							10.0	2.80
1526	0.64	30.3	40	381	21.9	11.2							8.4	2.60
1528	0.65	30.8	40	381	21.7	11.2							7.0	2.45
1530	0.65	31.3	40	381	21.8	11.2							5.9	2.25
1532	0.63	31.7	41	382	21.8	11.2	~32	0.32	0.34	73	71	757	5.3	2.15
1534	0.60	31.9	40	381	21.5	10.8	~32						2.4	1.70
1536	0.59	31.8	40	381	21.2	10.6	~32						0	0.60
1538	0.55	31.7	39	381	21.2	10.2							0	0.40

Table 8.2-V. CO₂ Concentration Unit Sea Level Test Data, Contd

TIME (minutes)	AIRFLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{accum} (psia)	H ₂ O ⁽²⁾ (ppm)	DC-331 T _{in} (° F)	DC-331 FLOW ⁽³⁾ ΔP (in. H ₂ O)	GLYCOL FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	SYSTEM A T _{hx-out} (° F)	LABORATORY AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)	LIVING AIR FLOW ⁽⁶⁾ ΔP (in. H ₂ O)	T _{lab} (° F)	T _{living} (° F)	P _{cabin} (mm Hg)	FLOWMETER 2F READING	P _{can} (psi)
1540	0.53	31.6	38	381	21.2	10.1							0	0.30
1540:50	No. 17 to inlet													
1541:25	Switched zeolite beds; zeolite bed No. 1 now desorbing.													
1542	0.46	31.3	37	381	20.3	10.0							>20	11.0
1542:30	Took CO ₂ accumulator purity sample.													
1543:30														
1544	0.48	30.0	38	381	19.7	9.3							>20	4.50
1544:30	Took CO ₂ accumulator purity sample; bleeding down accumulator.													
1545:30														
1546	0.50	20.1	38	381	8.8	9.2							11.5	2.4
1548	0.48	20.4	37	378	12.8	9.4							10.7	2.30
1550	0.47	20.4	36	378	15.2	10.2							15.4	3.00
1552	0.46	20.4	36	378	14.0	10.8							15.7	2.95
1552:26	No. 17 to accumulator													
1554	0.47	21.6	36	378	14.4	11.1							15.5	3.10
1556	0.49	23.2	36	378	15.7	11.1							19.1	3.70
1558	0.57	25.1	38	378	15.3	11.1							19.8	3.80
1600	0.63	26.9	36	378	15.2	11.1	~32	0.32	0.34	73	72		18.2	3.75
1602	0.67	28.5	36	378	15.2	11.1							15.9	3.50
1604	0.69	29.7	36	380	15.2	11.1							13.0	3.70
1606	0.71	30.8	36	380	15.3	11.1							10.3	2.90
1608	0.73	31.3	36	380	15.5	10.7							8.2	2.70
1609	added CO ₂ to cabin.													
1610	0.7	32.0	37	380	—	—							6.9	2.50
1612	0.70	32.5	37	380	15.6	11.2							5.7	2.35
1614	0.67	32.9	36	380	21.7	11.2	~32	0.32	0.34	72	71		3.5	1.90
1616	0.63	32.7	36	380	21.4	10.2							0	0.60
1618	0.59	32.5	35	381	21.5	10.5							0	0.35
1620	0.56	32.3	35	382	21.4	10.5							0	0.25
1620:50	No. 17 to inlet													
1621:20	Switched zeolite beds.													
1621:30	Turned CO ₂ concentration unit off; left 29.8 psia in accumulator.													

Table 8.2-VI. CO₂ Concentration Unit Sea Level Test; CO₂ Volume vs. Time*

TIME	CO ₂ VOLUME (percent)			TIME	CO ₂ VOLUME (percent)		
	ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM		ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM
1340			99.7	1504		0.31	99.0
1342	1.42	0.22		1506		0.22	98.9
1344	0.56	0.19		1508	0.60	0.21	
1346	0.50	0.19		1510		0.30	99.0
1348	0.51	0.19		1512	1.20	0.30	
1350	0.54	0.19		1514	0.53	0.22	
1352	0.62	0.20		1516	0.46	0.20	
1354	0.54	0.20		1518	0.46	0.20	
1356	0.51	0.20		1520	0.40	0.20	
1358	0.43	0.19		1522	0.42	0.19	
1400	0.50	0.20		1524	0.51	0.19	
1402	0.50	0.20		1526	0.52	0.20	
1404	0.50	0.20		1528	0.46	0.20	
1406	0.50	0.20		1530	0.51	0.21	
1408	0.50	0.22		1532	0.51	0.22	
1410	0.50	0.22		1534	0.51	0.23	
1412	0.50	0.22		1536	0.52	0.23	
1414	0.49	0.22		1538	0.46	0.24	
1416	0.49	0.22		1540	0.52	0.25	
1418	0.49	0.25		1542	0.56	0.43	
1420	0.49	0.26		1544		0.35	98.2
1422	0.46	0.30		1546		0.24	98.3
1424	0.50	0.22		1548	0.68	0.19	
1426		0.20	99.3	1550	0.69	0.20	
1428		0.18	99.4	1552	0.78	0.24	
1430	0.80	0.20		1554		0.19	
1432	0.78	0.21		1556	0.46	0.18	
1434	0.56	0.18		1558	0.46	0.17	
1436	0.50	0.18		1600	0.46	0.17	
1438	0.51	0.18		1602	0.46	0.17	
1440	0.49	0.18		1604	0.45	0.17	
1442	0.47	0.18		1606	0.43	0.18	
1444	0.46	0.18		1608	0.41	0.17	
1446	0.46	0.17		1610	0.46	0.18	
1448	0.46	0.18		1612	0.46	0.18	
1450	0.46	0.18		1614	0.48	0.18	
1452	0.51	0.19		1616	0.46	0.18	
1454	0.54	0.19		1618	0.46	0.19	
1456	0.54	0.20		1620	0.44	0.20	
1458	0.54	0.20		1622		0.35	
1500	0.53	0.20		1624			98.0
1502	0.60	0.45		1626			98.0

*Conducted 9 July 1965.

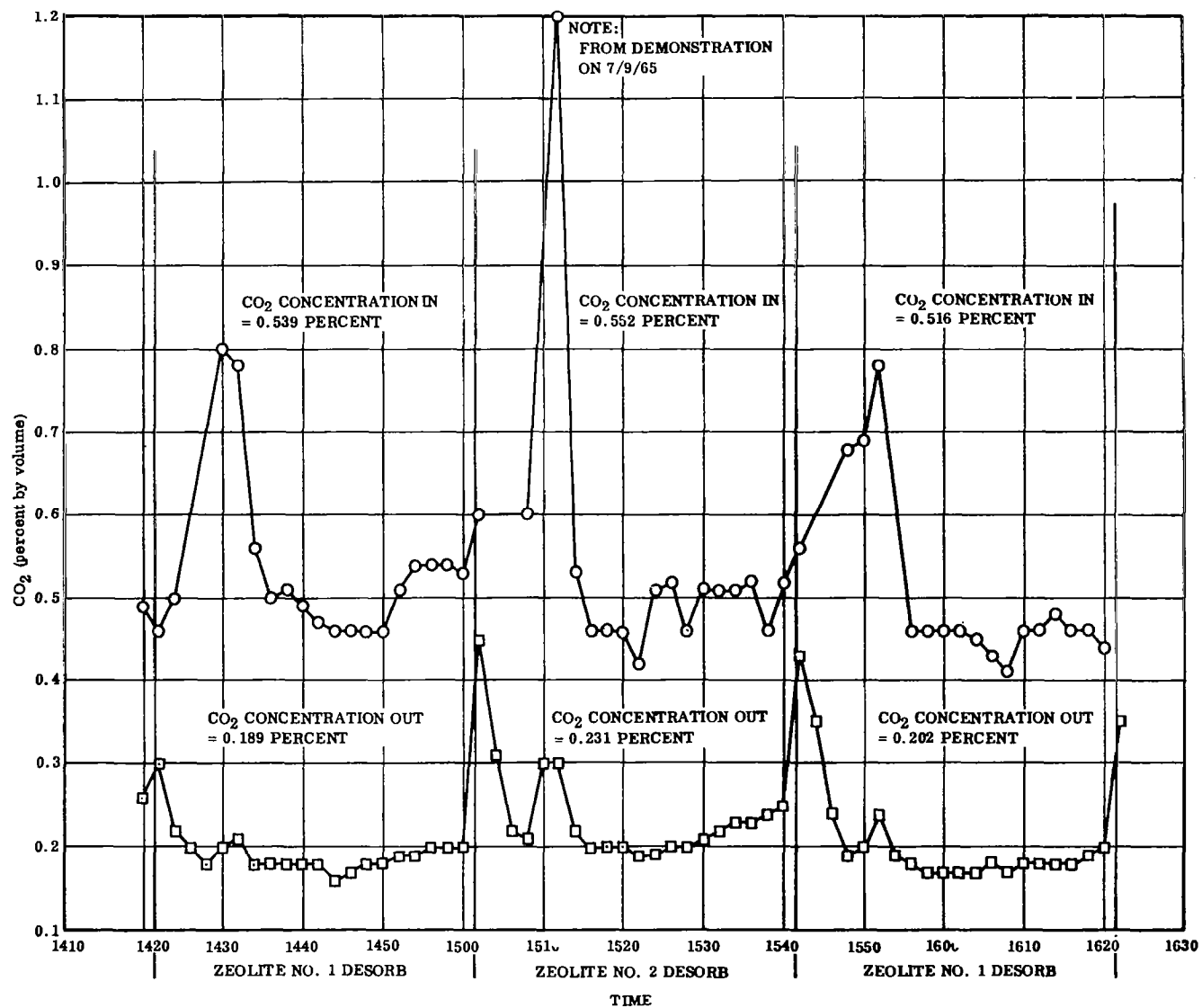
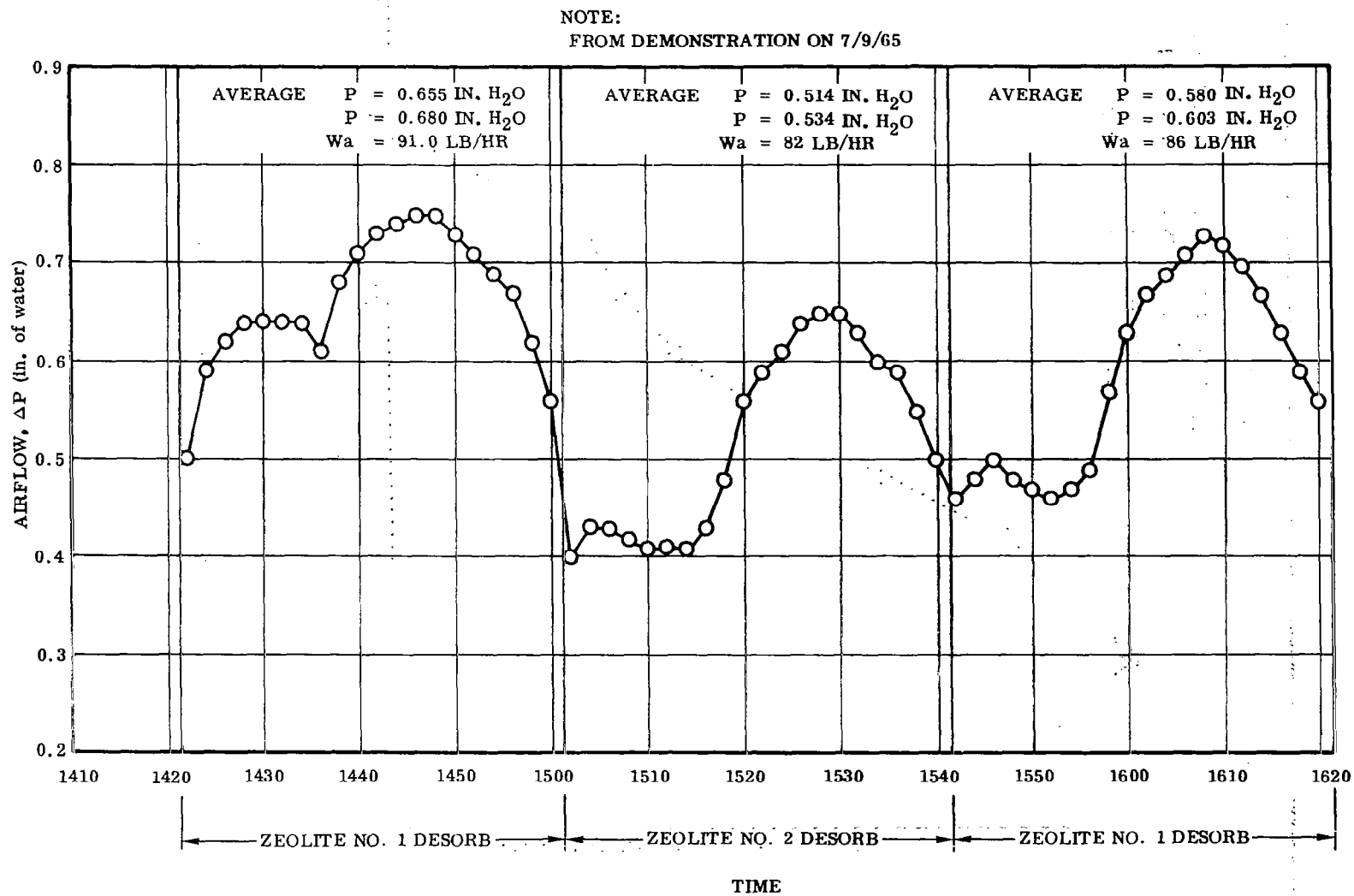


Figure 8.2-8. CO₂ Concentration Unit Purity

05-8

Figure 8.2-9. CO₂ Concentration Unit Air Flow

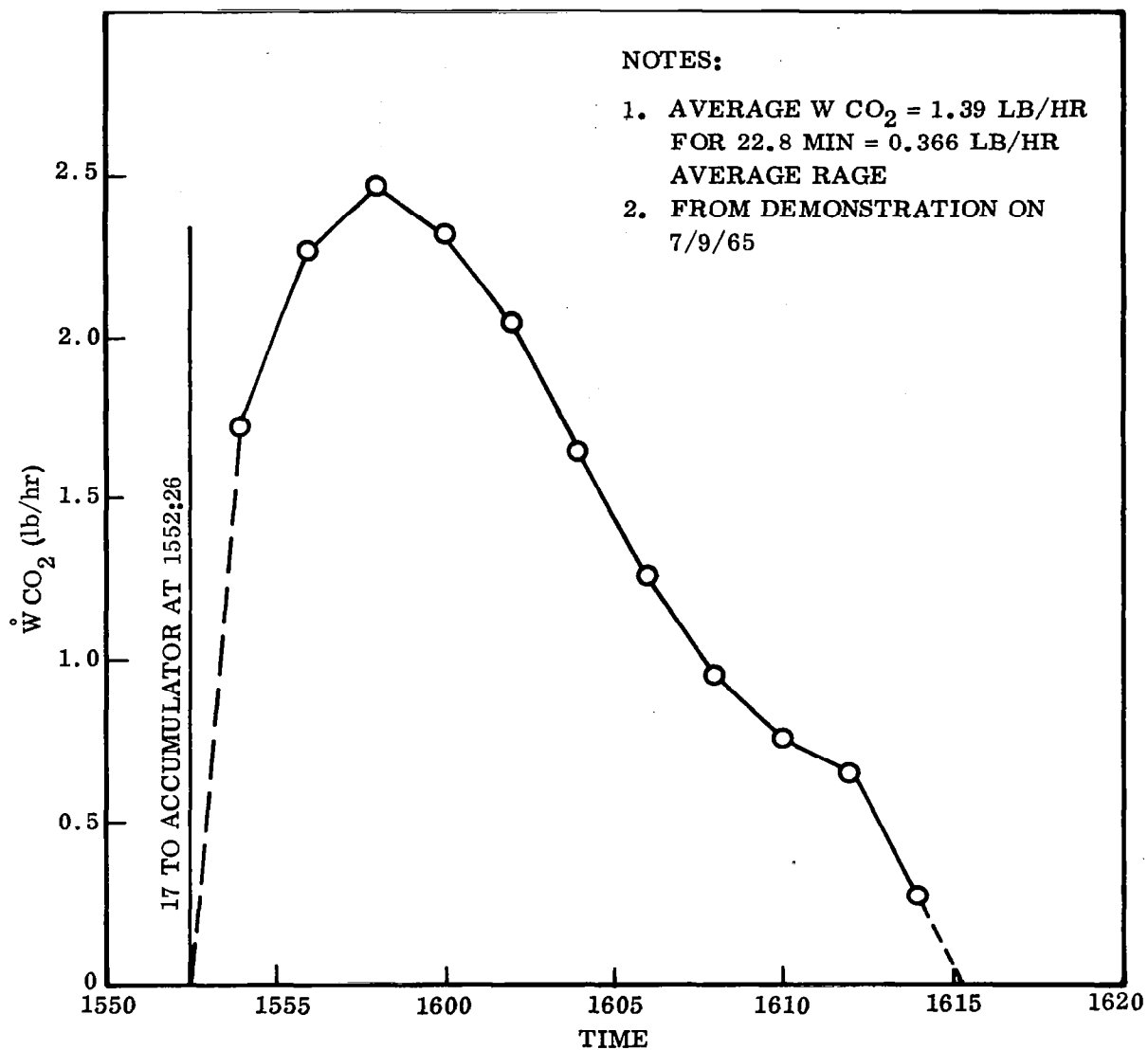


Figure 8.2-10. CO_2 Concentration Unit CO_2 Rates

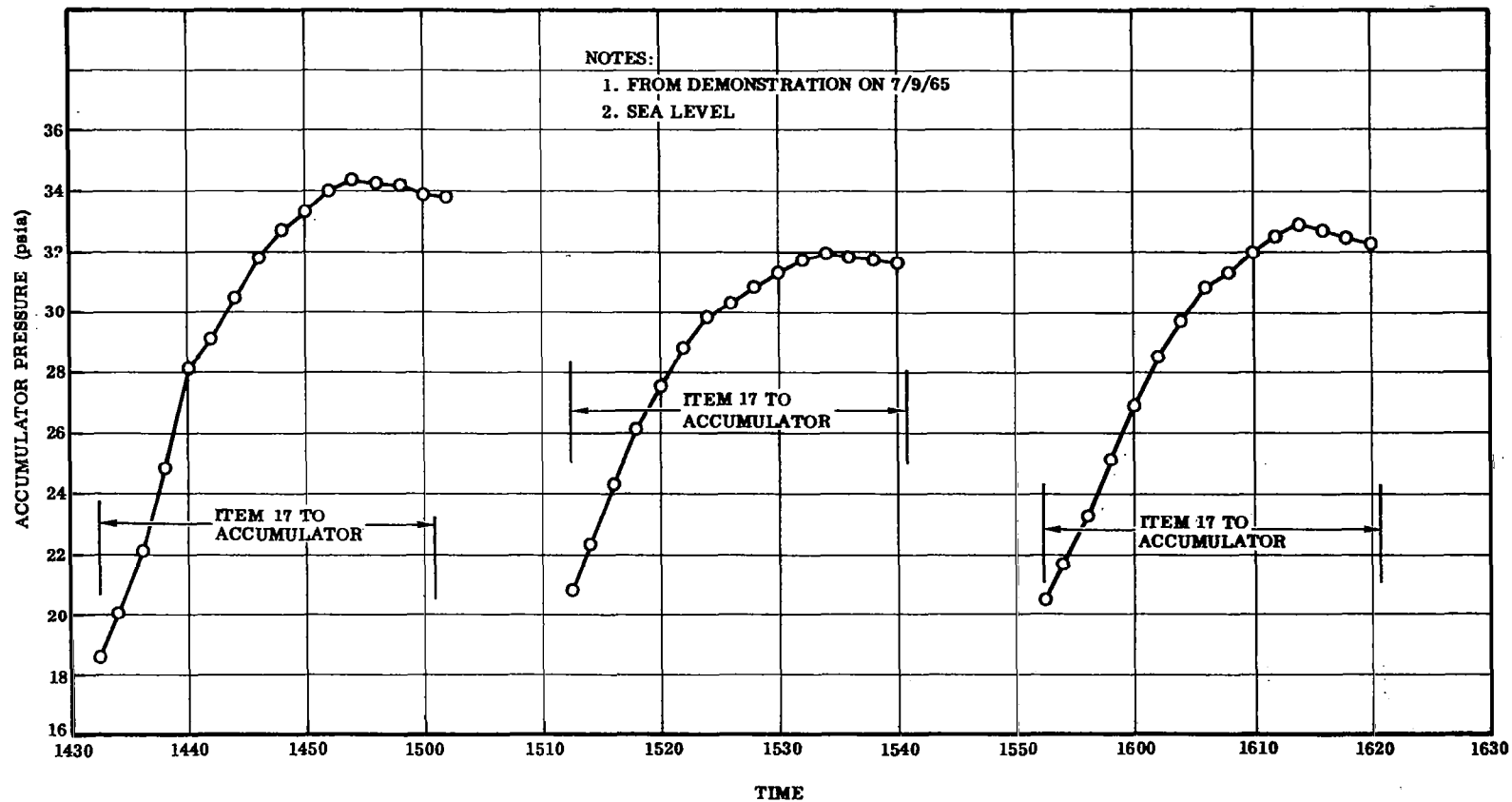


Figure 8.2-11. CO₂ Concentration Unit Accumulator Pressure History

middle half-cycle tested (Time 1501 to 1541, Zeolite Bed No. 1 Adsorb), it is seen from Figure 8.2-8 that integrated values of 0.552-percent and 0.23-percent CO₂ concentration at the inlet and outlet respectively were obtained. During the same time period a flow rate of 82 lb/hr was passed through the bed. With an air density of 0.078 lb/ft³, the volume air-flow rate was 1052 cfh. The volume flow rate of CO₂ was thus 1052 (0.552-0.231) = 3.38 cfh or 0.40 lb/hr adsorbed. From the flowmeters installed in the system, a CO₂ discharge flow history was obtained for the subsequent desorption of Zeolite Canister No. 1. This history is presented in Figure 8.2-10. The integrated value for CO₂ flow rate from this curve was 0.366 lb/hr, which checks very closely with the observed adsorption. However, the recorded change in accumulator pressure does not agree with the indicated delivery rate obtained from the flowmeters. Figure 8.2-11 presents accumulator-pressure history obtained during this test. For the time period in question, a pressure change from 20.4 psia to 32.8 psia was observed. Assuming pure CO₂ delivered, this corresponds to a delivery rate of 0.279 lb/hr. It may be observed, however, that accumulator pressure decreased at the end of desorption with a rate approximating 0.1 psi/min. If leakage in the system caused this decrease, then a CO₂ delivery rate of 0.135 lb/hr should be added to the observed rate yielding a total rate of 0.414 lb/hr. At this point it may only be said that an uncertainty exists in the determination of CO₂ delivery rate under these conditions but that a probable rate lies between 0.35 lb/hr and 0.40 lb/hr. Additional testing and careful evaluation will be necessary to more closely define these values.

Ten-psia Thermal-Desorption Performance. Definitive data describing system performance at 10 psia were obtained during the run of 10 June 1965 and are presented in Tables 8.2-VII and 8.2-VIII. The CO₂ purity was low at this time and changes in the cycle time of the CO₂ diverter valve (Item 17) were made subsequent to this run. This does not, however, alter any of the system characteristics except accumulator-pressure history. System temperatures for this run are presented in Figures 8.2-12 through 8.2-14. The cyclic nature of system temperatures may be observed from these plots. The fluid flows (DC-331 and propylene glycol) maintained during this test are presented in Figure 8.2-15).

Heat supplied to the unit through a typical half-cycle may be determined by obtaining integrated values for temperature and fluid flow. Consider the time period 1855 through 1935 during which Zeolite Canister No. 2 is being desorbed. The following time-averaged values are obtained for the DC-331 flow.

Temperature into unit	=	380° F; cp	=	0.443 Btu/lb-° F
Temperature into heat exchanger	=	310° F; cp	=	0.424 Btu/lb-° F
Temperature out of unit	=	257° F; cp	=	0.409 Btu/lb-° F
Fluid-flow rate	=	159 lb/hr		

Table 8.2-VII. CO₂ Concentration Unit 10-psia Test Data

TIME	AIR FLOW ⁽¹⁾ $\Delta P(\text{in. H}_2\text{O})$	P _{accum} (psia)	H ₂ O ⁽²⁾ (ppm)	DC-331 T _{in} (°F)	DC-331 FLOW ⁽³⁾ $\Delta P(\text{in. H}_2\text{O})$	GLYCOL FLOW ⁽⁴⁾ $\Delta P(\text{in. H}_2\text{O})$	SYSTEM A T _{hx-out} (°F)	LABORATORY AIR FLOW ⁽⁵⁾ $\Delta P(\text{in. H}_2\text{O})$	LIVING AIR FLOW ⁽⁶⁾ $\Delta P(\text{in. H}_2\text{O})$	T _{lab} (°F)	T _{living} (°F)	COOLANT HEATER TEMP. (°F)
1740	Started CO ₂ concentration unit; desorbing SG bed No. 2 and zeolite bed No. 2.											
1750	0.26	19.2	140	378	17.2	4.3	33.0	0.23	0.23	66	65	40
1752	0.29	20.6	140	378	17.1	4.4	33.0	0.23	0.23	66	65	40
1753	Turned coolant heater on.											
1754	0.31	22.0	150	378	17.2	4.2	33.0	0.23	0.23	67	65	42
1758	0.32	24.0	132	378	17.8	4.2	33.0	0.23	0.23	67	65.5	55
1800	0.33	24.3	115	378	18.0	4.1	33.0	0.23	0.23	67	65.5	59
1802	0.33	24.6	112	378	18.0	4.1	33.0	0.23	0.23	67	65.5	72
1804	0.34	24.5	111	378	18.0	4.1	33.0	0.23	0.23	67	65.5	79
1806	0.34	24.3	111	378	18.1	4.1	33.0	0.23	0.23	67	65.5	80
1808	0.34	23.8 ⁽⁷⁾	110	378	18.8	4.1	33.0	0.23	0.23	67	65.5	85
1810	0.34	23.3	110	378	17.7	4.1	33.0	0.23	0.23	67	65.5	88
1814	0.33	23.3	110	379	17.6	3.8	33.0	0.23	0.23	67	65.5	
1814:59	No. 17 to inlet.											
1815:22	Switched zeolite beds: Zeolite Bed No. 1 now desorbing.											
1816	0.33	23.3	110	379	16.6	3.8	33.0	0.23	0.23	67	65.5	97
1818	0.33	23.3	110	379	16.3	3.8	33.0	0.23	0.23	67	65.5	
1820	0.34	23.3	110	379	9.0	4.1	33.0	0.23	0.23	67	65.5	99
1822	0.34	23.3	110	377	10.5	4.5	33.0	0.23	0.23	67	65.5	100
1824	0.34	23.6	110	376	13.0	4.6	33.0	0.23	0.23	67	66.0	102
1826	0.34	24.9	110	377	13.2	4.5	33.0	0.23	0.23	68	66.0	102
1828	0.34	26.2	110	375	12.8	4.5	33.0	0.23	0.23	68	66.0	
1830	0.32	28.2	110	375	13.8	4.4	33.0	0.23	0.23	68	66.0	
1832	0.36	30.5	110	377	14.1	4.2	33.0	0.23	0.23	68	66.0	102
1834	0.36	32.6	110	377	14.2	4.2	33.0	0.23	0.22	69	66.0	
1836	0.37	34.7	110	377	14.5	4.2	33.0	0.23	0.22	69	66.0	
1838	0.39	36.4	Readjust	378	14.7	4.2	33.0	0.23	0.22	69	66.0	102
1840	0.40	37.5	100	378	14.8	4.2	33.0	0.23	0.22	69	66.0	
1842	0.40	38.2	100	378	14.8	4.2	33.0	0.23	0.22	69	66.0	

(1) Orifice Calibration of 5/19/65

(2) @ 122.5 cc/min and 2.0 psia

(3) Orifice H104-F

(4) Orifice K105-F

(5) Orifice A108-F

(6) Orifice A109-F

(7) Accumulator sample valve was open; now closed.

Table 8.2-VII. CO₂ Concentration Unit 10-psia Test Data, Contd

TIME	AIR FLOW ⁽¹⁾ ΔP(in. H ₂ O)	P _{accum} (psia)	H ₂ O ⁽²⁾ (ppm)	DC-331 T _{in} (°F)	DC-331 FLOW(3) ΔP(in. H ₂ O)	GLYCOL FLOW ⁽⁴⁾ ΔP(in. H ₂ O)	SYSTEM A T _{hx-out} (°F)	LABORATORY AIR FLOW ⁽⁵⁾ ΔP(in. H ₂ O)	LIVING AIR FLOW ⁽⁶⁾ ΔP(in. H ₂ O)	T _{lab} (°F)	T _{living} (°F)	COOLANT HEATER TEMP. (°F)
1844	0.41	38.9	100	378	14.9	4.2	33.0	0.23	0.22	69	66.0	
1846	0.40	39.2	106	379	14.9	4.2	33.0	0.23	0.22	69	66.0	
1848	0.40	39.3	118	379	18.8	4.2	33.0	0.23	0.22	69	66	
1850	0.40	39.4	120	379	18.1	3.8	33.0	0.23	0.22	69	66	103
1852	0.40	39.3	118	380	18.0	4.2	33.0	0.23	0.22	69.0	66.0	
1854	0.38	39.3	112	380	17.9	3.8	33.0	0.23	0.22	69.0	66.0	
1854:55	No. 17 to inlet.											
1855:20	Switched zeolite beds; zeolite bed No. 2 now desorbing.											
1856	0.32	39.3	108	380	16.8	3.7	33.0	0.23	0.23	69.0	66.0	104
1858	0.32	Taking sample	105	380	16.5	3.6						
1858:15 }	Bleeding accumulator.											
1900:15 }												
1900	0.32		103	380	11.2	3.6	33.0	0.23	0.23	69.0	66.0	
1902	0.32	16.4	101	379	12.0	4.2	33.0	0.23	0.23	69.0	66.0	
1904	0.32	16.8	100	377	14.8	4.5	33.5	0.23	0.23	69.0	67	104
1906	0.31	18.2	98	378	13.8	4.4	33	0.23	0.23	70	67	
1908	0.30	19.8	98	378	15.1	4.3	33	0.23	0.23	70	67	
1910	0.28	22.4	97	379	17.2	4.2	33	0.22	0.22	70	67	
1912	0.31	24.9	96	379	17.5	4.2	33	0.22	0.22	70	67	103
1914	0.31	27.3	96	379	17.5	4.2	33	0.22	0.22	70	67	
1918	0.32	30.8	95	379	17.9	4.2	33	0.22	0.22	70	67	
1920	0.33	32.2	94	380	18.1	4.2	33	0.22	0.22	70	67	
1922	0.34	33.2	95	380	18.2	4.2	33	0.23	0.22	70	67	102
1924	0.34	34.2	96	380	18.2	4.2	33	0.23	0.22	70	67	
1926	0.34	34.8	105	380	18.3	4.2	33	0.23	0.22	70	67	
1928	0.34	35.3	118	380	18.6	4.1	33	0.23	0.22	70	67	
1930	0.34	35.3	122	380	18.0	4.0	33	0.23	0.22	70	67	
1932	0.34	35.3	121	380	17.9	3.9	33	0.23	0.22	70	67	
1934	0.33	35.3	115	380	17.9	3.8	33	0.23	0.22	70	67	

(1) Orifice Calibration of 5/19/65

(2) @ 122.5 cc/min and 2.0 psia

(3) Orifice H104-F

(4) Orifice K105-F

(5) Orifice A108-F

(6) Orifice A109-F

(7) Accumulator sample valve was open; now closed.

Table 8.2-VII. CO₂ Concentration Unit 10-psia Test Data, Contd

TIME	AIR FLOW(1) ΔP(in. H ₂ O)	P _{accum} (psia)	H ₂ O(2) (ppm)	DC-331 T _{in} (°F)	DC-331 FLOW(3) ΔP(in. H ₂ O)	GLYCOL FLOW(4) ΔP(in. H ₂ O)	SYSTEM A T _{hx-out} (°F)	LABORATORY AIR FLOW(5) ΔP(in. H ₂ O)	LIVING AIR FLOW(6) ΔP(in. H ₂ O)	T _{lab} (°F)	T _{living} (°F)	COOLANT HEATER TEMP. (°F)
1934:58	No. 17 to inlet.											
1935:18	Switched zeolite beds; zeolite bed No. 1 desorbing.											
1936	0.33	35.3	115	380	16.9	3.7	33	0.23	0.22	70	67	
1938	0.33	Taking sample	107	380	16.7	3.7	33	0.23	0.22	70	67	
1938:30 } 1938:40 }	Bleeding of accumulator.											
1940	0.33	17.2	102	380	9.1	3.7	33	0.23	0.22	70	67	
1942	0.33	17.8	101	377	11.0	4.2	33	0.23	0.22	70	67	
1944	0.33	18.0	100	377	13.0	4.5	33	0.23	0.22	70	67	
1946	0.33	19.3	98	378	12.7	4.4	33	0.23	0.22	70	67	
1948	0.32	20.8	97	378	13.2	4.2	33	0.23	0.22	70	67	103
1950	0.31	23.1	95	378	14.1	4.2	33	0.23	0.22	70	67	
1952	0.34	25.2	95	378	14.4	4.2	33	0.23	0.22	70	67	
1954	0.36	27.8	95	379	14.4	4.1	33	0.23	0.22	70	67	102
1956	0.36	29.8	93	379	14.7	4.1	33	0.23	0.22	70	67	
1958	0.37	31.2	93	379	14.7	4.1	33	0.23	0.22	70	67	
2000	0.38	32.5	92	380	14.8	4.1	33	0.23	0.22	70	67	
2002	0.39	33.8	93	380	14.8	4.1	33	0.23	0.22	70	67	
2004	0.39	34.4	100	380	15.0	4.1	33	0.23	0.22	70	67	
2006	0.39	35.0	130	380	15.0	4.1	33	0.23	0.22	70	67	
2008	0.39	35.5	142	380	18.2	4.0	33	0.23	0.22	70	67	
2010	0.39	35.5	140	380	18.0	3.9	33	0.23	0.22	70	67	
2012	0.39	35.4	130	380	18.0	4.3	33	0.23	0.22	70	67	
2014	0.38	35.3	120	380	18.0	4.2	33	0.23	0.22	70	67	
2014:55	No. 17 to inlet.											
2015:19	Switched zeolite beds; zeolite bed No. 2 now desorbing.											

(1) Orifice Calibration of 5/19/65

(2) @ 122.5 cc/min and 2.0 psia

(3) Orifice H104-F

(4) Orifice K105-F

(5) Orifice A103-F

(6) Orifice A109-F

(7) Accumulator sample valve was open; now closed.

Table 8.2-VIII. CO₂ Concentration Unit 10-psia Test; CO₂ Volume vs. Time

TIME	CO ₂ VOLUME (percent)			TIME	CO ₂ VOLUME (percent)		
	ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM		ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM
1752	0.90	0.35		1818		0.45	
1754	0.90	0.35		1920		0.45	
1756		0.40		1922		0.45	
1758		0.40		1924		0.45	
1800		0.40		1926	0.92	0.45	
1802		0.40		1928		0.45	
1804		0.40		1930		0.45	
1806		0.40		1932		0.45	
1808	0.90	0.40		1934		0.50	
1810		0.40		1936		0.50	89
1812		0.45		1938		0.75	
1814		0.45		1940		0.55	
1816		0.50		1942		0.50	
1817		0.90		1944		0.40	
1818	0.90	0.65		1946		0.40	
1820		0.50		1948		0.38	
1822		0.45		1950		0.35	
1824		0.45		1952		0.35	
1826		0.40		1954		0.35	
1828		0.40		1956		0.35	
1830		0.35		1958		0.35	
1832		0.35		2000	0.90	0.35	
1834		0.35		2002		0.35	
1836		0.35		2004		0.38	
1838	0.90	0.35		2006		0.40	
1840		0.35		2008		0.42	
1842		0.35		2010		0.45	
1844		0.35		2012		0.55	
1846		0.35		2014		0.60	
1848		0.40		2016		0.80	90
1850		0.40		2018		0.70	
1852		0.45		2020		-	
1854		0.45		2022		0.60	
1856		0.80		2024		0.55	
1857		1.00		2026		0.50	
1858		0.80		2028		0.50	99.1†
1900		0.60	74	2030		0.50	
1902		0.50		2032		0.50	
1904		0.45		2034		0.50	
1906	0.95	0.45		2036		0.50	98.9†
1908		0.45		2038		0.50	
1910		0.45		2040		0.50	
1912		0.45		2042		0.50	
1914		0.45		2044		0.50	90
1916		0.45					

*Conducted 10 June 1965.

†From zeolite canister.

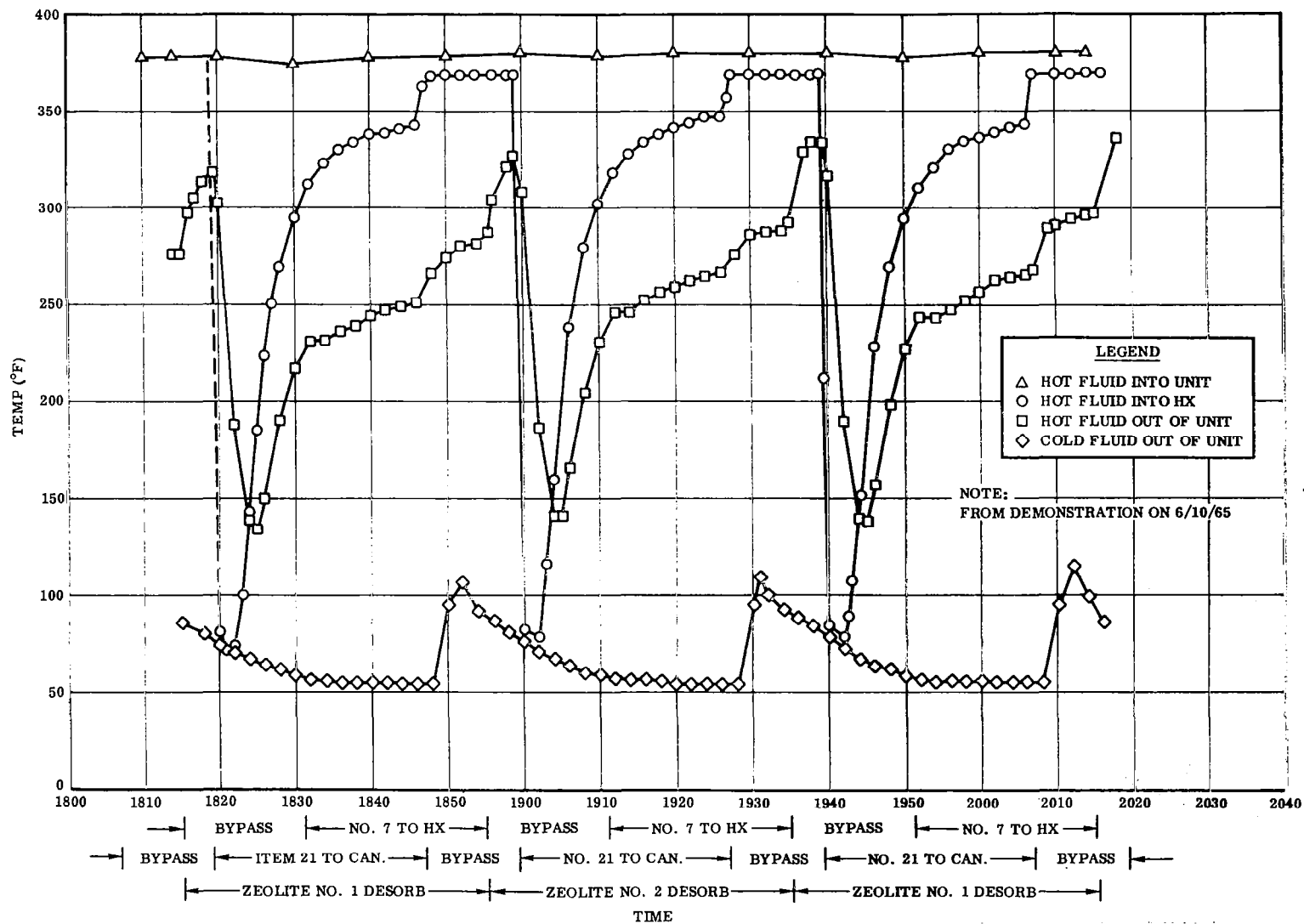


Figure 8.2-12. CO₂ Concentration Unit Fluid Temperature History; 10-psia Test

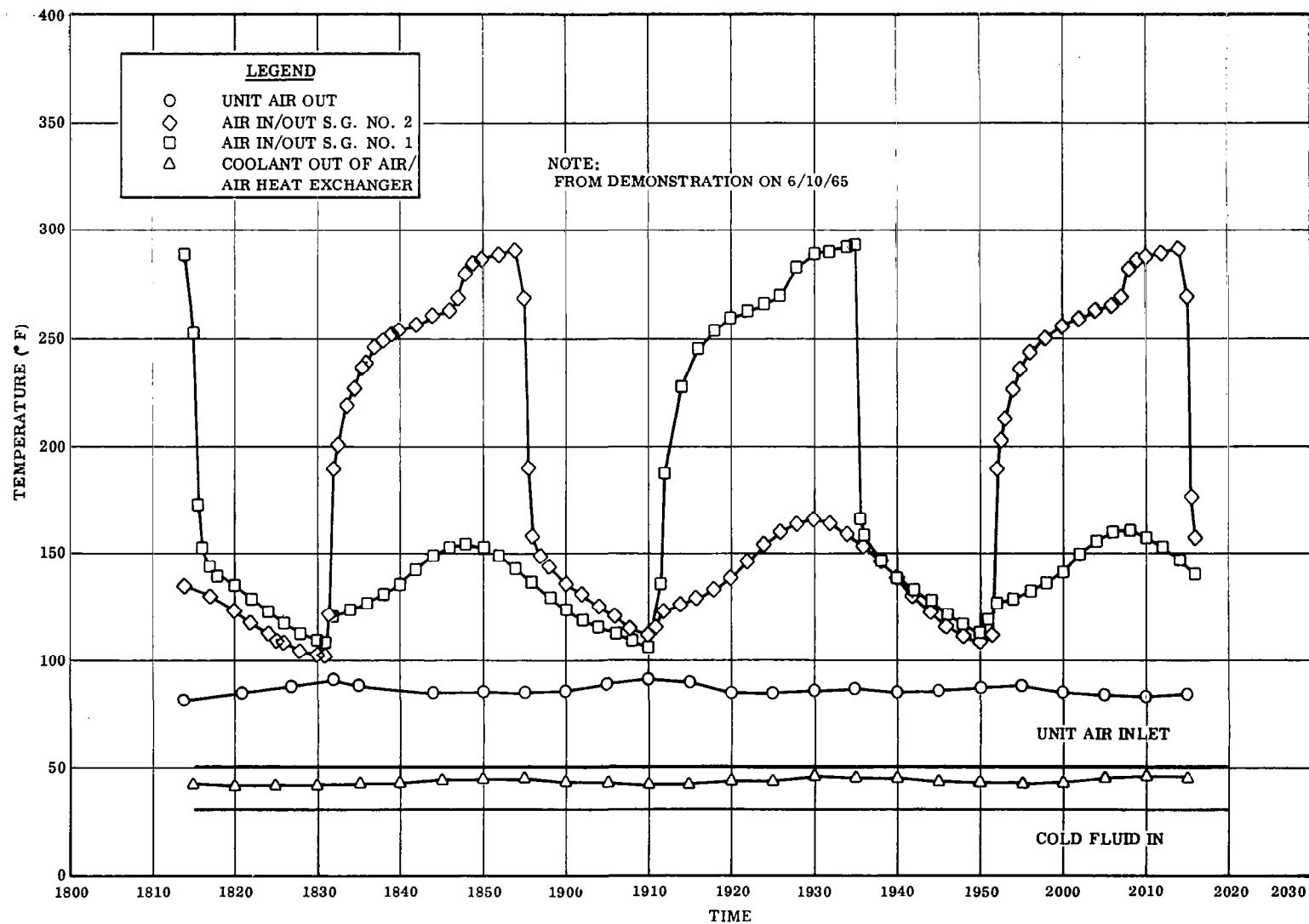


Figure 8.2-13. CO₂ Concentration Unit Air Temperature History; 10-psia Test

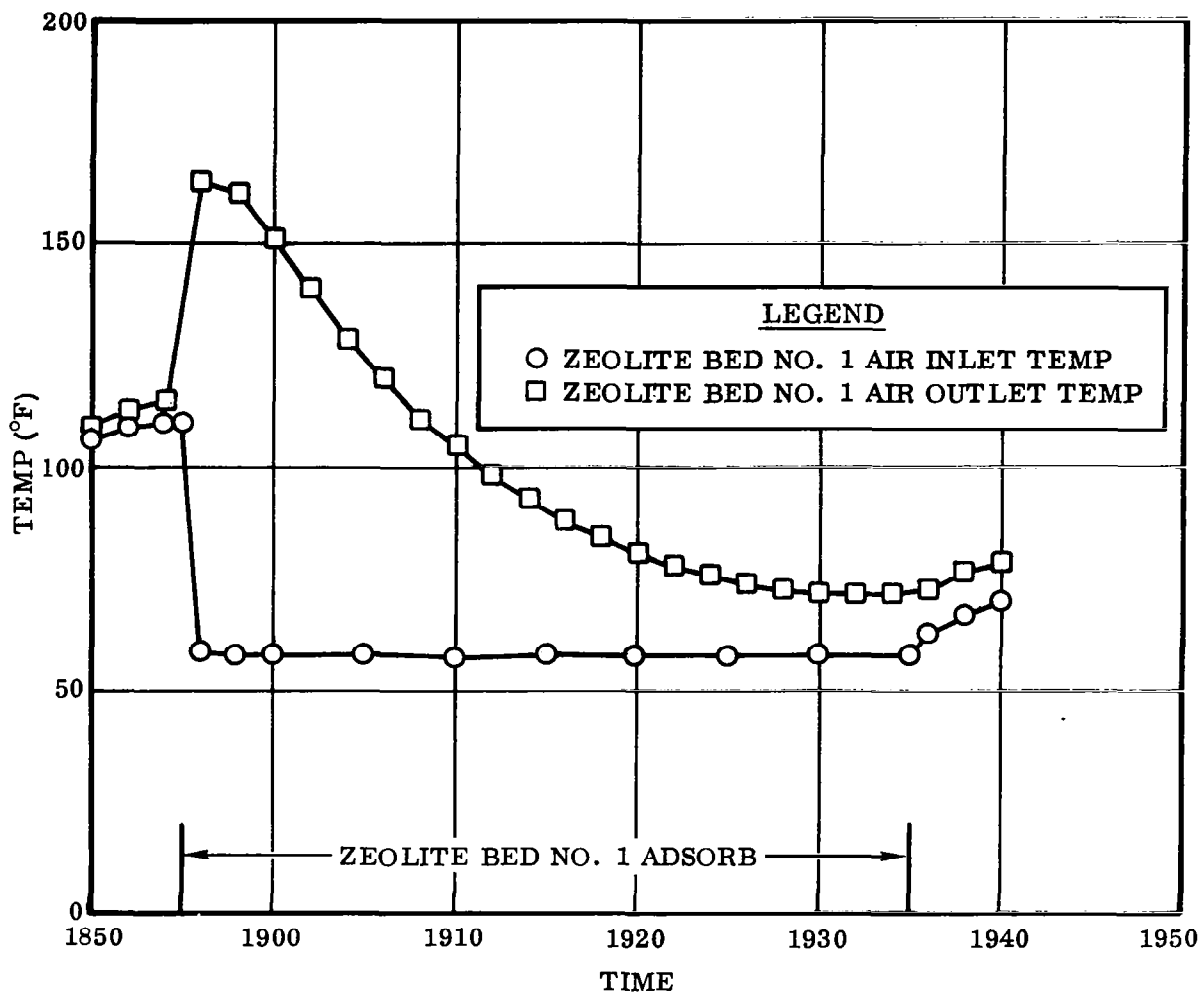


Figure 8.2-14. CO₂ Concentration Unit Adsorbing Zeolite Bed Air Temperature History; 10-psia Test

19-8

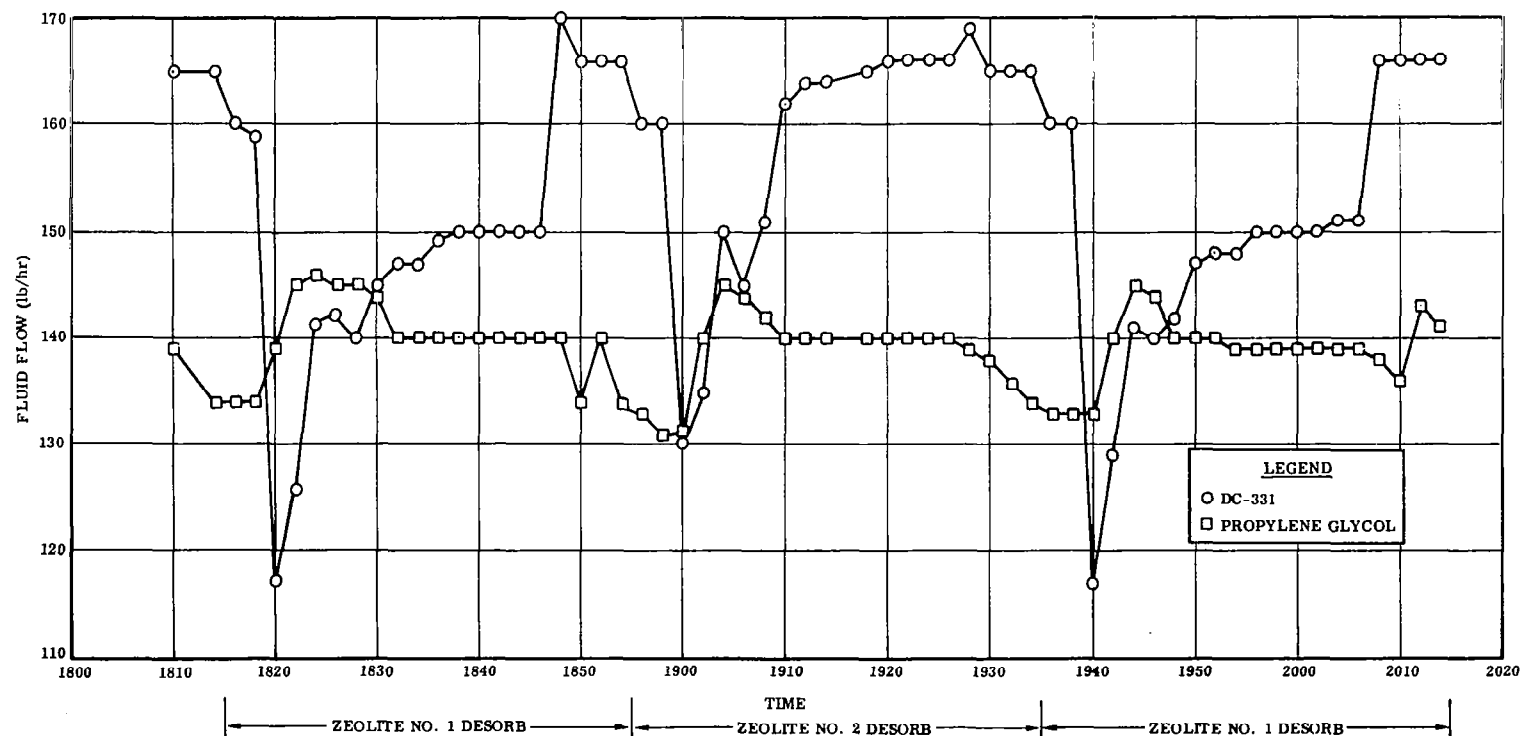


Figure 8.2-15. Process Heat and Coolant Fluid Flow

$$\begin{aligned}\text{Heat rejected to the zeolite bed} &= 159 (380 \times 0.443 - 310 \times 0.424) = 159 \times 36.8 \\ &= 5850 \text{ Btu/hr}\end{aligned}$$

$$\begin{aligned}\text{Heat rejected through the heat exchanger} &= 159 (310 \times 0.424 - 257 \times 0.409) = 159 \\ &\times 26.5 = 4210 \text{ Btu/hr}\end{aligned}$$

During the same period, an average air flow of 55.6 lb/hr was passed through the unit. Heat rejected from the unit through the air stream was $55.6 \times 0.24 (85 - 50) = 467 \text{ Btu/hr}$.

Intermediate stages of heat transfer are:

Heat transfer across air-to-air heat exchanger is given by:

Coolant flow rate = 139 lb/hr

Coolant inlet temperature = 31° F

Coolant discharge temperature (from heat exchanger) = 44° F

$$Q = 139 \times 0.89 (44-31) = 1610 \text{ Btu/hr}$$

Heat transferred to the air stream from the adsorbing silica gel bed is obtained from:

Air inlet temperature to silica gel bed = 50° F

Air inlet temperature to zeolite bed = 58° F

$$Q = 1610 \text{ (from above)} + 56 \times 0.24 (58-50) = 1610 + 108 = 1718 \text{ Btu/hr}$$

The total heat rejected to the coolant flow may be determined from coolant-fluid unit inlet and discharge temperatures and coolant-fluid flow rate. From Figure 8.2-12, fluid-discharge temperature averaged over the half-cycle time is 67.5° F. $Q = 139 \times 0.89 (67.5-31) = 4510 \text{ Btu/hr}$. Of this amount, 1610 Btu/hr was added through the air-to-air heat exchanger leaving 2900 Btu/hr rejected through the intermediate-fluid heat exchanger.

From this analysis it may be seen that 10,060 Btu/hr was supplied to the unit in the DC-331 flow. The air stream carried away 467 Btu/hr and 4510 Btu/hr was rejected to the propylene glycol coolant. It would thus appear that 5083 Btu/hr was rejected to the ambient air.

The CO₂ concentration across the adsorbing zeolite bed is shown in Figure 8.2-16, which presents both inlet and outlet concentration and system air flow.

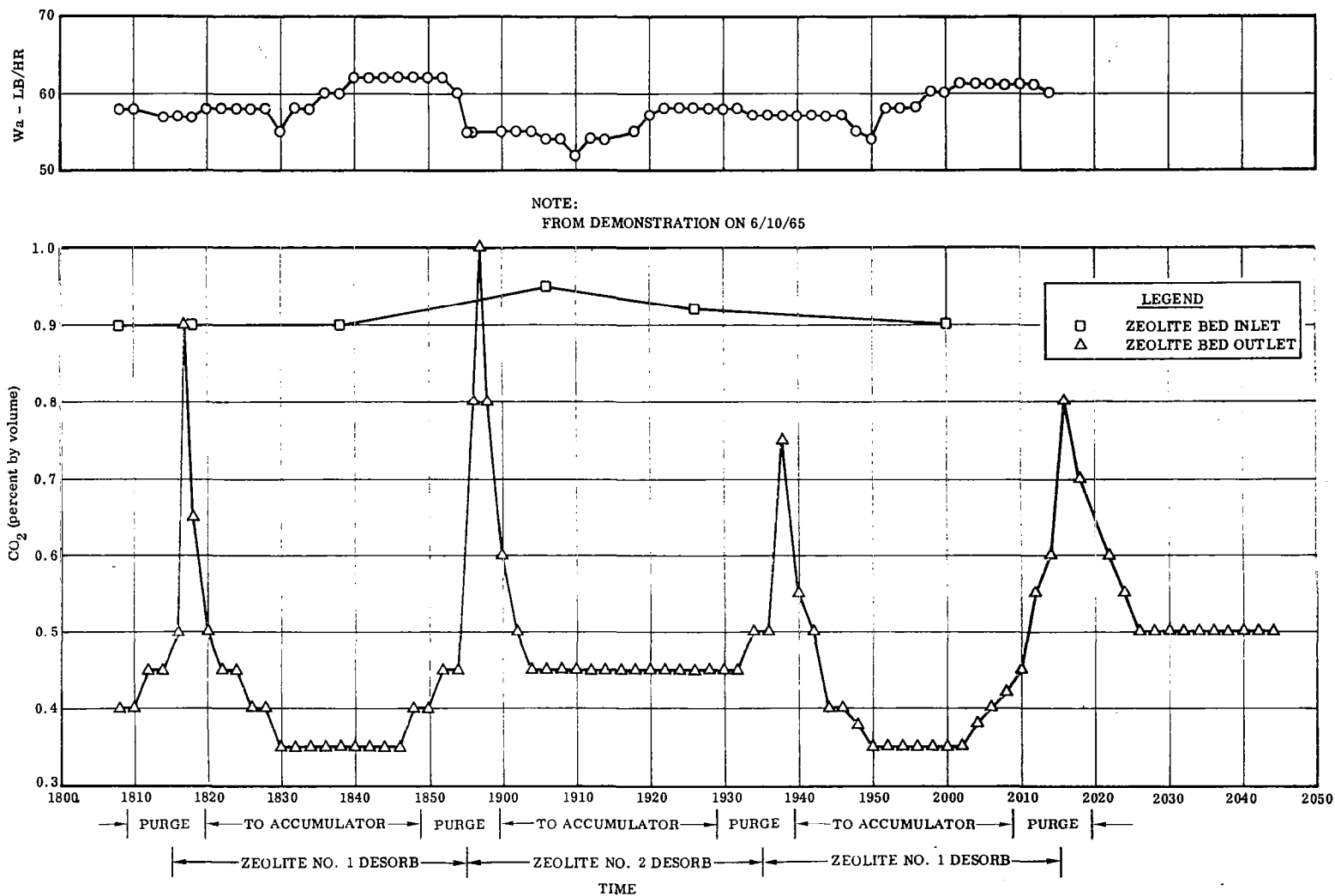


Figure 8.2-16. CO₂ Inlet and Outlet Concentration and Air Flow

During the time 1855 through 1935, air flow average value was 55.6 lb/hr and inlet and outlet CO₂ volume concentration was 0.93 percent and 0.47 percent respectively. With air density = 0.053 lb/ft³, volume air flow = 55.6/0.053 = 1050 cfh. Quantity of CO₂ adsorbed = 1050 (0.93 - 0.47)/100

$$= 4.83 \text{ cfh}$$

or

$$= 4.83/360 (44) = 0.591 \text{ lb/hr}$$

From Figure 8.2-17 which presents accumulator-pressure history, it is seen that accumulator pressure increased from 17.2 psia to 35.4 psia during the subsequent cycle when the previously adsorbing canister was in the desorbing mode. Assuming a CO₂ purity of 90 percent as obtained from chromatographic analysis at the end of this desorption period, the amount of pure CO₂ delivered to the accumulator was

$$\begin{aligned} W_{\text{CO}_2} &= \frac{1.5 (35.4 - 17.2) (144) (1.95)}{35.1 \times 530} \\ &= 0.412 \text{ lb/hr} \end{aligned}$$

This checks reasonably well with the deduced value previously presented for the sea-level condition and indicates a cyclic efficiency of about 70 percent. From other indirect indications, this value would appear to be high, but more work is necessary to define performance more accurately.

Ten-psia Vacuum-Desorption Performance. The unit was run using vacuum desorption for a total test time of slightly less than 5 hours. A typical run wherein definitive information was recorded was run on 18 June 1965. Data recorded from this run are presented in Tables 8.2-IX and 8.2-X. Additional system temperatures recorded during this run are presented in Figures 8.2-18 and 8.2-19. It may be observed from Table 8.2-X that inlet CO₂ concentration averaged about 0.84 percent (volume) and zeolite-bed outlet concentration was about 0.30 percent (volume) during this run. For an average air flow of approximately 56 lb/hr, this amounts to an adsorption rate of 0.70 lb/hr, which is slightly higher than observed in the previously discussed thermal desorption run at 10 psia. Since vacuum desorption is accomplished using the same heat application as in thermal desorption, it is possible that the bed is more completely desorbed each cycle, thereby permitting a higher capacity in the adsorption mode. This possible higher capacity is not fully defined by the few hours of operation thus far obtained on the unit, and more testing is required to establish adsorption and desorption capacity in this mode.

Delivered CO₂ Purity. As testing progressed and more definite performance characteristics were obtained from the unit, it became apparent that something more than system leakage was responsible for the low observed purity of the CO₂ collected in the accumulator. A purging system was rigged into the test bed to permit purging the CO₂ accumulator with bottled CO₂ until a purity in excess of 99.5 percent was obtained. System

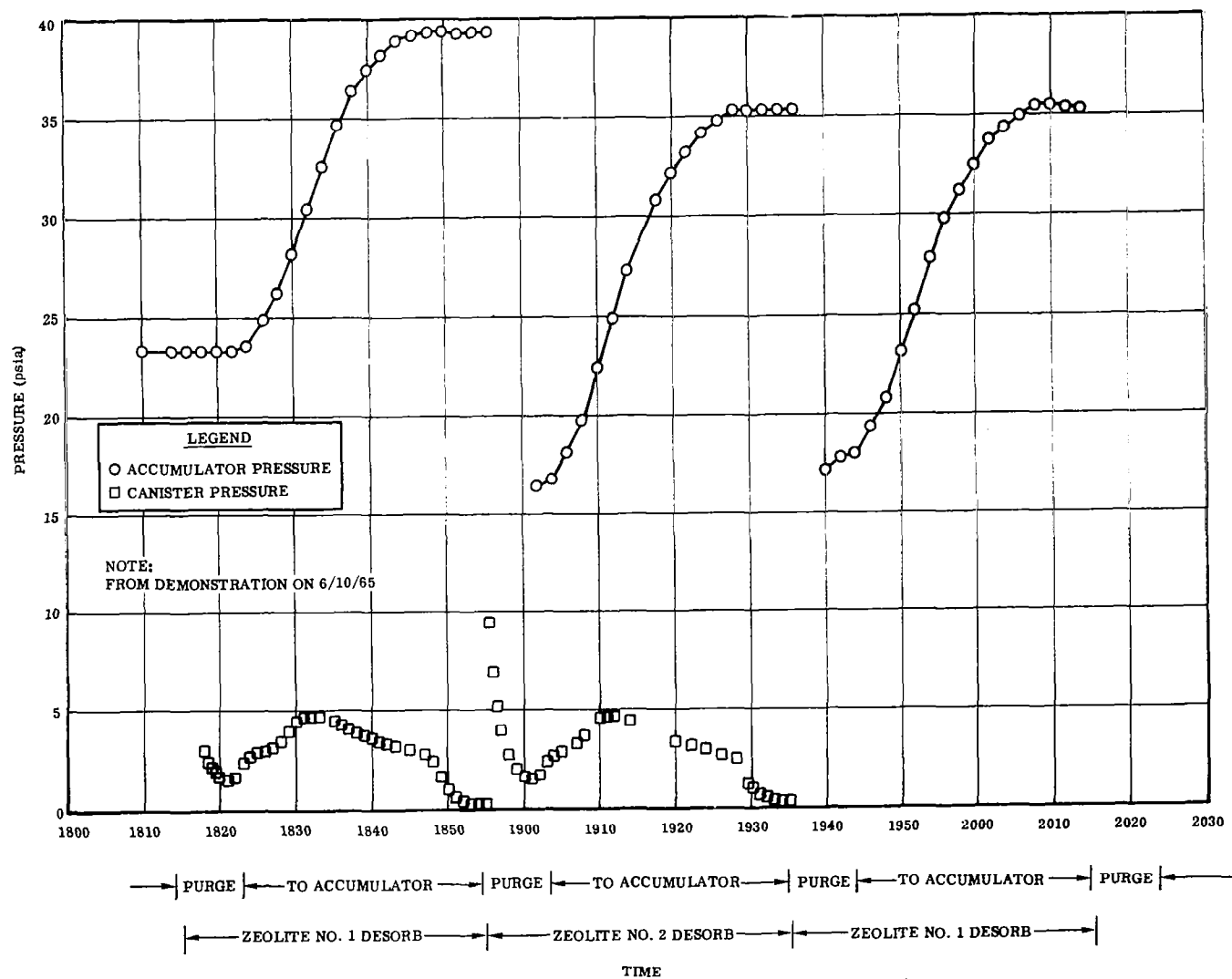


Figure 8.2-17. Accumulator-Pressure History

Table 8.2-IX. 10-psia Vacuum Desorption Test Data

TIME	AIRFLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{canister} (mm Hg)	H ₂ O (ppm)	DC-331	DC-331	GLYCOL	SYSTEM A	LABORATORY	LIVING	T _{lab} (° F)	T _{living} (° F)	P _{cabin} (mm Hg)
				T _{in} (° F)	FLOW ⁽³⁾ ΔP (in. H ₂ O)	FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	T _{hx-out} (° F)	AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)	AIR FLOW ⁽⁶⁾ ΔP (in. H ₂ O)			
1918	0.28											
1920	0.28		130	382	20.5	8.5	33	0.22	0.21			
1922	0.33		138	382	20.5	8.5	33	0.22	0.21	72	64	492
1924	0.34		140	383	20.5	8.5	33	0.22	0.19	72	64	496
1926	0.36	100	150	382	20.4	8.5	33	0.23	0.23	73	64.5	500
1928	0.37	50	165	382	20.3	8.5	33	0.23	0.23	73	64.5	500
1930	0.38	28	360	382	19.8	8.5	33	0.23	0.23	73	64.5	500
1932	0.38	25	420	382	19.8	8.5	33	0.23	0.23	73	64.5	502
1934	0.39	25	390	382	23.0	8.5	33	0.23	0.23	73	65	502
1936	0.39	25	320	382	22.2	8.5	33	0.23	0.23	73	65	502
1938	0.38	25	280	385	21.8	8.6	33	0.23	0.23	73	65	502
1940	0.38	0.55	250	385	21.8	8.0	33	0.23	0.23	73	65	502
1942	0.32	500	220	385	21.4	7.6	33	0.23	0.23	73	65	502
1944	0.31	180	210	383	21.6	7.1		0.23	0.23	73	65.5	502
1946	0.30	140	200	383	13.0	6.9	34	0.23	0.23	74	65.5	502
1948	0.30	150	180	383	18.2	7.0	34	0.23	0.23	74	65.5	502
1950	0.30	4.5	180	382	18.2	7.5	34	0.23	0.23	74	65.5	502
1952	0.30	2.3	180	381	20.4	8.0	34	0.23	0.23	74	65.5	502
1954	0.29	1.05	175	382	23.4	8.5	34	0.23	0.23	74	65.5	502
1956	0.28	0.60	170	382	24.2	8.5	33.5	0.23	0.23	74	65.5	502
1958	0.30	0.46	160	383	24.1	8.5	33.0	0.23	0.23	74	65.5	502
2000	0.30	0.40	158	383	24.2	8.5	33.0	0.23	0.23	74	65.5	502
2002	0.30	0.40	155	383	23.5	8.5	33.0	0.23	0.23	74	65.5	502
2004	0.32	0.40	155	383	22.5	8.5	33.0	0.23	0.23	74	66	502
2006	0.32	0.40	152	384	22.1	8.5	33.0	0.23	0.23	74	66	502
2008	0.32	0.40	150	384	22.0	8.3	33.0	0.23	0.23	74	66	502
2010	0.33	0.41	155	384	21.8	8.3	33.0	0.23	0.23	74	66	502
2012	0.32	0.41	192	384	21.6	8.4	33.0	0.23	0.23	74	66	502
2014	0.32	0.39	198	383	22.0	8.4	33.0	0.23	0.23	74	66	502
2016	0.32	0.28	190	383	21.5	7.5	33.0	0.23	0.23	74	66	502
2018	0.32	0.22	180	383	21.4	8.0	33.0	0.23	0.23	74	66	502

(1) Orifice calibration of 5/19/65

(2) @ 2 psi and 125 cc/min

(3) Orifice H104-F

(4) Orifice K105-F

(5) Orifice A108-F

(6) Orifice A109-F

(7) Air evaporation units now off

(8) Air lock pumped down

Table 8.2-IX. 10-psia Vacuum Desorption Test Data, Contd

TIME	AIRFLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{canister} (mm Hg)	H ₂ O (ppm)	DC-331 T _{in} (° F)	DC-331 FLOW ⁽³⁾ ΔP (in. H ₂ O)	GLYCOL FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	SYSTEM A T _{hx-out} (° F)	LABORATORY AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)	LIVING AIR FLOW ⁽⁶⁾ ΔP (in. H ₂ O)	T _{lab} (° F)	T _{living} (° F)	P _{cabin} (mm Hg)
2020	0.30											
2021:42	Switched zeolite beds; zeolite bed No. 1 desorbing now.											
2022	0.31	500	160	383	22.0	7.3	33.0	0.23	0.23	74.5	66	502
2024	0.30	140	155	383	21.6	7.0	33.0	0.23	0.23	74.5	66	502
2026	0.31	120	155	383	10.3	6.8	33.5	0.23	0.23	74.5	66.5	502
2028	0.31	120	150	383	14.8	6.8	34.0	0.23	0.23	74.5	66.5	502
2030	0.31	4.6	150	383	18.1	7.0	33.5	0.23	0.23	75	67	502
2032	0.31	2.5	145	381	15.9	7.9	33.5	0.23	0.23	75	67	502
2034	0.30	1.1	145	381	17.9	8.5	33.5	0.23	0.23	75	67	502
2036	0.29	0.59	142	381	19.3	8.5	33.0	0.23	0.23	75	67	502
2038	0.31	0.41	141	381	19.7	8.6	33.0	0.23	0.23	75	67	502
2040	0.33	0.35	141	383	19.6	8.4	33.0	0.23	0.23	75	67	502
2042	0.34	0.34	141	383	19.6	8.4	33.0	0.23	0.23	75	67.5	502
2044	0.35	0.34	140	383	19.3	8.4	33.0	0.23	0.23	75	67.5	502
2046	0.36	0.34	140	383	19.4	8.4	33.0	0.23	0.23	75	67.5	502
2048	0.37	0.35	140	383	19.4	8.4	33.0	0.23	0.23	75	67.5	502
2050	0.37	0.36	175	383	19.5	8.4	33.0	0.23	0.23	75	67.5	502
2052	0.38	0.38	240	383	19.5	8.4	33.0	0.23	0.23	75	67.5	502
2054	0.38	0.35	250	383	22.5	8.4	33.0	0.23	0.23	75	67.5	502
2056	0.37	0.28	240	383	21.6	7.5	33.0	0.23	0.23	75	67.5	502
2058	0.36	0.22	210	383	21.5	8.1	33.0	0.23	0.23	75	67.5	502
2100	0.36	0.48	192	383	21.6	7.8	33.0	0.23	0.23	75	67.5	502
2101:04	No. 17 to inlet											
2101:30	Switched zeolite beds; zeolite bed No. 2 now desorbing.											
2102	0.30	400	175	383	20.8	7.3	33.0	0.23	0.23	75	67.5	502
2104	0.30	120	170	383	21.0	7.0	34.0	0.23	0.23	75	67.5	502
2106	0.29	110	160	383	12.7	6.9	34.5	0.23	0.23	75	67.5	502
2108	0.29	105	155	383	18.0	6.7	34.5	0.23	0.23	75	67.5	502
2110	0.29	5.2	150	383	18.4	7.0	34.5	0.23	0.23	75	67.5	502
2112	0.29	2.4	146	385	20.0	7.8	34.0	0.23	0.23	75	67.5	502
2114 ⁽⁷⁾	0.28	1.1	142	383	23.0	8.5	34.0	0.23	0.23	75	67.5	502
2116	0.27	0.60	140	383	22.7	8.5	34.0	0.23	0.23	75	67.5	502
2117:10	Silica gel beds switched; SG bed No. 1 now desorbing.											
2118	0.28	0.40	138	385	23.5	8.5	34.0	0.23	0.23	75	67.5	502
2120	0.29	0.35	135	385	23.6	8.5	33.5	0.23	0.23	75	67.5	502

[illegible]

Table 8.2-X. 10-psia Vacuum Desorption Test; CO₂ Volume vs. Time

TIME	CO ₂ VOLUME (percent)		TIME	CO ₂ VOLUME (percent)	
	ZEOLITE BED IN	ZEOLITE BED OUT		ZEOLITE BED IN	ZEOLITE BED OUT
1847	0.75		2040		0.30
1900		0.38	2045		0.30
1908		0.18	2050		0.30
1910		0.18	2055		0.30
1915		0.18	2100		0.35
1920		0.18	2102		0.40
1923	0.62		2103		0.45
1930		0.22	2104		0.25
1933		0.23	2105	0.84	
1940	0.80	0.28	2107		0.28
1945		0.30	2115		0.32
1950		0.30	2120		0.32
1953	0.82		2125		0.30
1955	0.82	0.30	2130		0.35
2000		0.30	2135		0.35
2002		0.30	2140		0.40
2005		0.30	2144		0.40
2008		0.30	2145		0.25
2010	0.84	0.35	2150	0.84	0.25
2015		0.35	2154		0.60
2020		0.35	2155		0.70
2025		0.25	2200	0.82	0.80
2030		0.30	2215	0.84	
2035		0.30			

*Conducted 18 June 1965

07-8

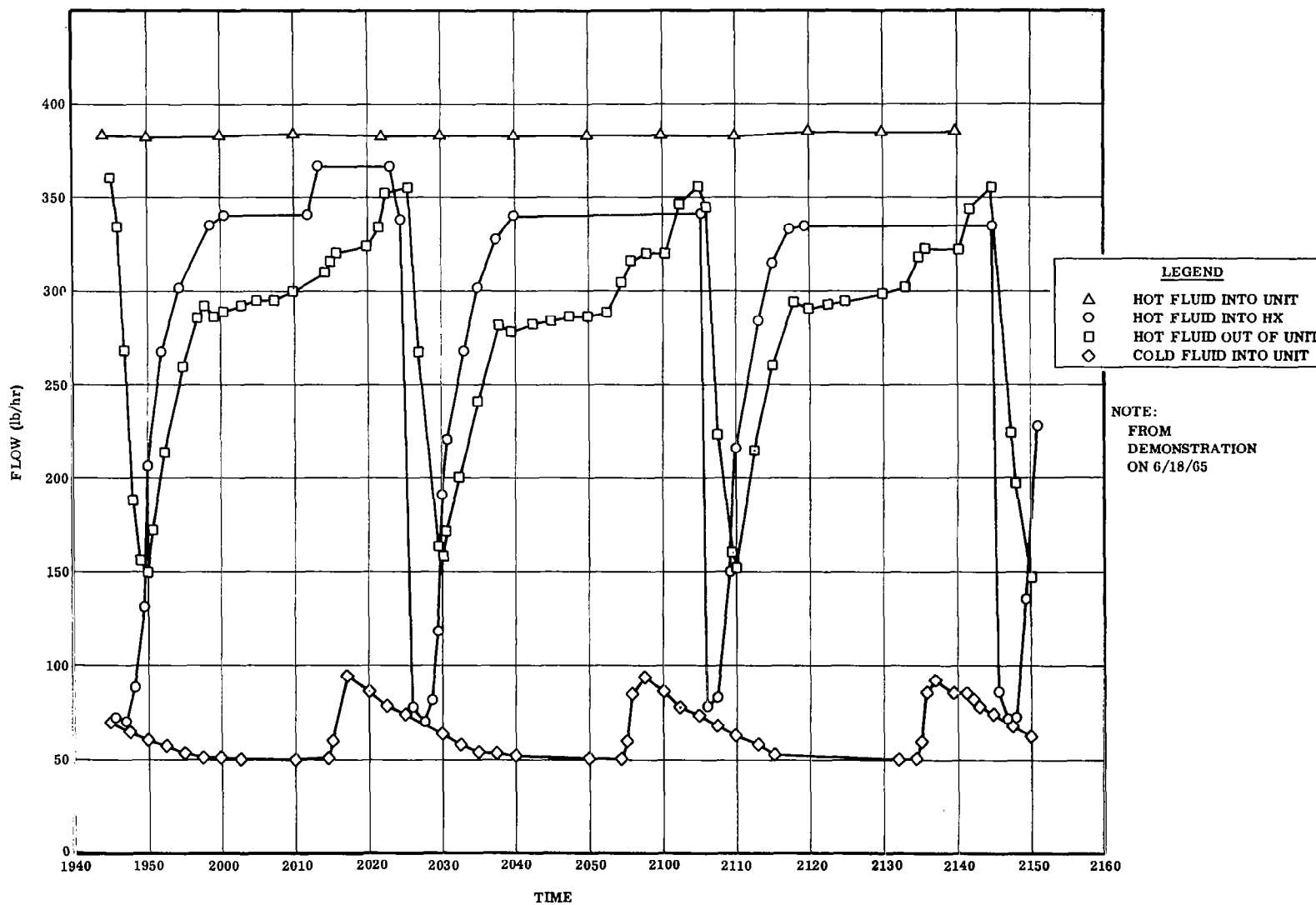


Figure 8.2-18. Vacuum Desorption Test

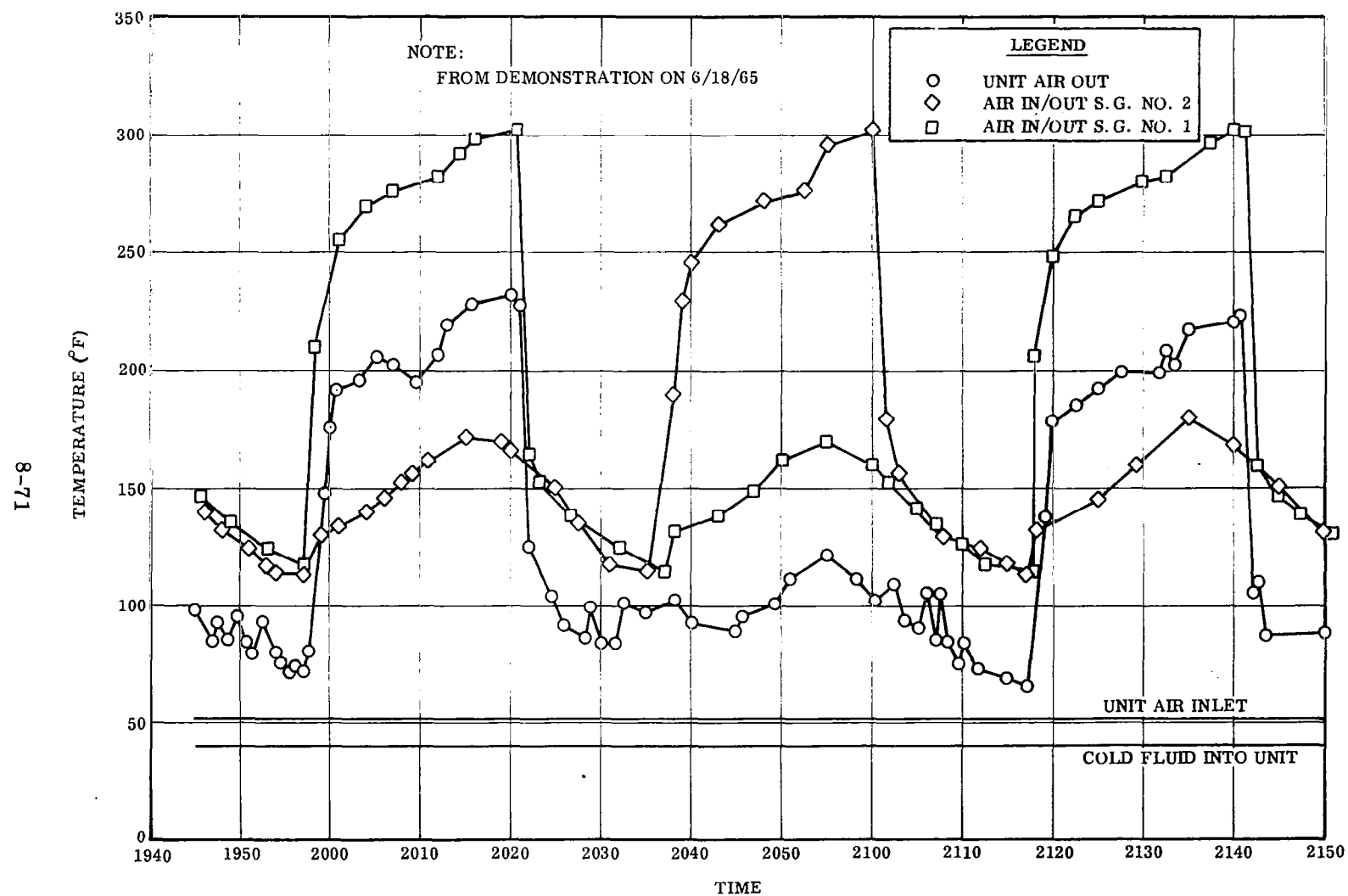


Figure 8.2-19. CO₂ Concentration Unit 10-psia Vacuum Desorption Test

tests were then initiated and CO₂ desorbed to the accumulator. After each desorption cycle, accumulator purity was determined. The accumulator was then relieved of the accumulated gases to a pressure slightly above ambient, CO₂ from the next desorption cycle was collected, and CO₂ purity again ascertained. This procedure was continued until an equilibrium value for CO₂ purity was obtained. Initial tests run without using this procedure, but simply checking CO₂ purity in the accumulator after having started from some unknown base yielded results ranging from 70-percent to 80-percent purity after about three cycles of operation. To further define the problem area, gas samples were taken at the discharge of the CO₂ transfer pump to obtain a history of CO₂ purity in the gas being delivered to the accumulator. These tests showed a low purity at the beginning of CO₂ transfer. Results of this survey taken in the run of 24 June 1965 are presented in Figure 8.2-20. The purge cycle for these runs was as presented in the timing chart (Figure 8.2-6) was approximately 8.5 minutes. From Figure 8.2-20 it is seen that CO₂ purity was low during approximately 13 minutes or about 5 minutes after the CO₂ transfer valve had directed flow to the accumulator. It is also indicated in Figure 8.2-20 that CO₂ purity was low at the end of the CO₂ delivery cycle. This was not a true indication, however, and it was determined that this indication was caused by the gas-sampling system pulling a suction on a dead-ended sampling line. This caused pressure in the sampling line to become negative, and ambient air was sucked into the chromatograph to produce a false analysis. In the light of these findings, it seemed apparent that the purge cycle required adjustment. A series of tests was therefore initiated to determine equilibrium accumulator purity using various purging times. Five runs were made during which cycle times were changed from the original 8.5 minutes to a maximum of about 13 minutes in incremental steps. A set of flowmeters was also added to the system to measure the quantity of gas being delivered to the accumulator as a check against the delivery rate as determined from accumulator-pressure history. Some interesting results were obtained from these flowmeter readings, which indicated that a great quantity of gas is delivered from the bed during the purge cycle and the initial portion of the delivery cycle. Time did not permit more than a cursory analysis of test data, but preliminary indications seemed to be that far more gas was delivered from the bed than could be accounted for from adsorption data and consideration of the purging of gases from the interstitial volumes.

The accumulator purity determined as a function of purge time is presented in Figure 8.2-21. From these findings it appears that a definite decrease in collected CO₂ purity will be incurred if the purge time is decreased to less than 11 minutes. The final timing of the unit was therefore set to incorporate a purge time of essentially 11 minutes. It was desired to hold the minimum possible purge time since process rate will be adversely affected by increasing the purge time. As an indication of the change in process rate as a function of purge time, the data from these runs were normalized to represent the rate anticipated at a unit inlet CO₂ concentration of 0.5 percent. The resulting process rate (from accumulator-pressure history) is also presented in Figure 8.2-21. It is evident that purity and process rate must be considered simultaneously in evaluating appropriate purge cycles.

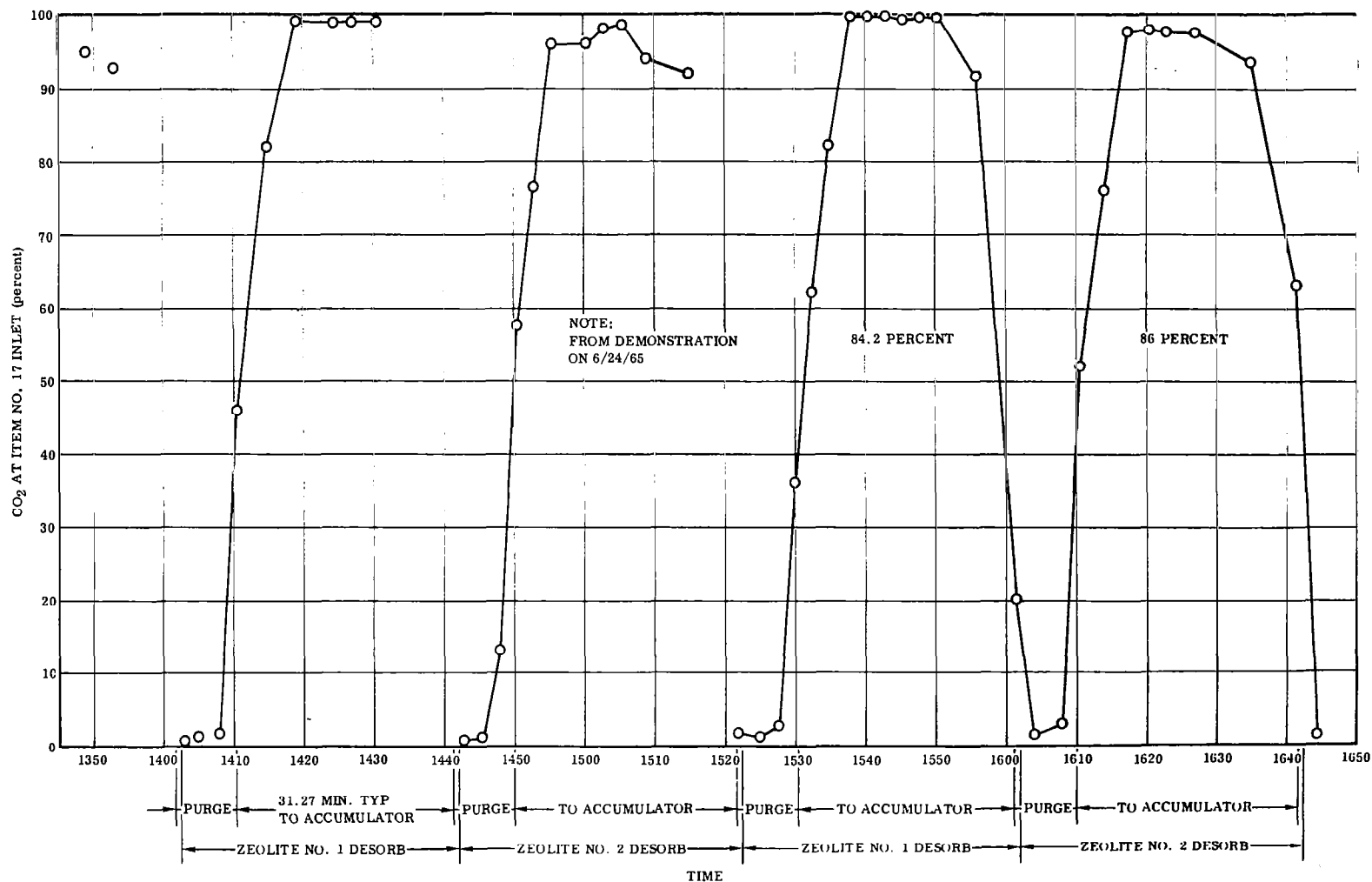


Figure 8.2-20. CO₂ Concentration Unit Thermal Desorption Purity Test

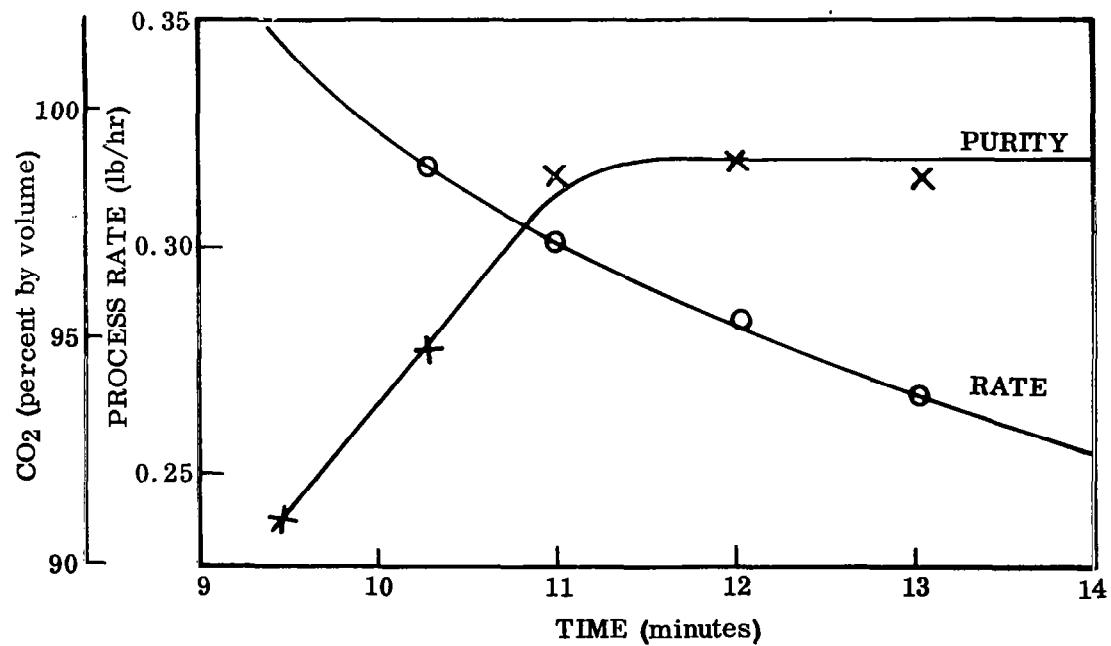


Figure 8.2-21. CO₂ Concentration Unit Accumulator Purity vs. Purge Time

8.2.1.4 Final Demonstration Tests

Ten-psia Thermal Desorption. The unit was run in the thermal-desorption mode as an integrated part of the oxygen-regeneration system. Prior to the start of this test, the unit was started and operated over a period of time at sea-level conditions. The purpose of this preliminary run was, first, to dry the silica gel beds prior to admitting process air to the zeolite beds; second, to adsorb and transfer CO₂ to the accumulator to ensure a supply of CO₂ to the reduction unit during the starting sequence. A third purpose of the sea-level operation was to check proper unit operation and to effect integration of the oxygen-regeneration system prior to demonstration so that if faults existed, these could be remedied at this time. The operation at sea level was successfully concluded and the unit secured to begin the tests at reduced pressure. No data were recorded for these sea-level runs. The oxygen-regeneration system was started with the test bed closed and at 520 mm Hg. The valves transferring CO₂ from the accumulator to the reduction unit was initially in dump position, and the CO₂ in the accumulator was lost. The accumulator was quickly recharged from a bottle to 30 psia, and a start was accomplished.

The test continued from 1400 hours until approximately 1745 hours, at which time it was concluded that essentially 2 hours of steady-state operation had been achieved. Approximately two and one-half 80-minute cycles had been completed, which resulted in 5 canister desorptions with attendant CO₂ transfers to the accumulator. The measured purity of the CO₂ in the accumulator at the end of test was 98.9 percent by volume. No operational problems developed during the test and shutdown was at the decision of the test conductor with agreement from the NASA LRC representatives.

Data recorded during this test are presented in Tables 8.2-XI and 8.2-XII.

The timing sequence of the unit utilized for these tests is that presented in Figure 8.2-7. By reference to this sequencing chart and the notation of cyclic events entered in the data log sheets, valve positions at any time may be determined. For purpose of illustration, integrated values of the parameters displayed in Figures 8.2-22 and 8.2-23 have been derived for the half-cycle time from 1522 through 1602. During this time, Zeolite Canister No. 1 was being desorbed while Zeolite Canister No. 2 was adsorbing CO₂. This is a representative operational condition and the values thus obtained may be regarded as typical with respect to this test. The following averaged values were obtained for the half-cycle considered.

Process Air

Process air flow (W_a)	61.4 lb/hr
Air inlet temperature	53° F
Air outlet temperature	114° F

Table 8.2-XI. NASA 10-psia Demonstration Thermal Desorption Run Test Data

TIME	AIR FLOW ⁽¹⁾	P _{accum}	H ₂ O	DC-331	DC-331	GLYCOL	SYSTEM A	LABORATORY	LIVING	T _{lab}	T _{living}	P _{cabin}	CO ₂ FLOW	CO ₂ FLOW	P _{can}
	ΔP (in. H ₂ O)	(psia)	(ppm)	T _{in}	FLOW ⁽²⁾	FLOW ⁽³⁾	T _{hx-out}	AIR FLOW ⁽⁴⁾	AIR FLOW ⁽⁵⁾	(°F)	(°F)	(mm Hg)	3F	2F	(psia)
1400	Started system to begin 10-psia demonstration test.														
1405	0.36	Recharged accumulator to 30 psia from bottle.													
1410	0.36	30.0	220	377	22.6	16.6	29.0	2.2	0.3	72	63	520	14.6		5.0
1415	0.40	32.0	210	377	23.5	16.6	29	0.24	0.30	73	63	520	10.2		5.6
1417:30	Silica gel cycled to No. 2 desorber.														
1427	0.41	36.0	170	375	23.5	16.4	29	0.28	0.30	74	63	523		9.5	3.1
1432	0.41	34.3	155	375	23.5	16.4	30	0.28	0.30	74	63	525		6.4	2.5
1438	0.40	32.0	150	375	27.5	15.8	30	0.28	0.30	74	63.5	525		0	0.2
1441:30	31.0 No. 17 to accumulator.														
1442:50	Zeolite cycled to No. 2 desorber.														
1443	0.32	30.5	145	375	25.2	14.5	31	0.28	0.30	74.5	64.0	526	10.5		3.9
1457	0.30	29.2	140	375	27.8	15.5	31	0.28	0.30	76	64.5	528		18.8	4.5
1504	0.34	33.5	140	375	27.8	16.0	31	0.28	0.30	76	64.5	529		12.0	3.4
1515	0.37	34.2	170	375	26.6	15.3	31	0.28	0.30	76.5	65.0	529		0	1.6
1522:20	Zeolite cycled to No. 1 desorber. At 1525, taped two air outlets in living compartment to increase temperature.														
1530	0.36	28.8	150	375	22.2	12.5	32.0	0.35	0.29	77	65.0	530	8.0		3.0
1540	0.39	30.0	80	380	24.8	14.5	32	0.34	0.29	78	65	530		15.5	3.9
1552	0.40	32.0	130	378	23.8	15.1	31	0.35	0.28	78	66.5	530		6.0	2.4
1557	0.40	31.0	110	380	26.5	15.0	31	0.35	0.28	78	66.5	530		0	0.3
1602:15	Zeolite cycled to No. 2 desorber.														
1613	0.40	24.5	60	377	pegged	13.4	31	0.36	0.28	79	66.5	532	8.5		4.4
1628	0.35	31.0	60	377	27.2	15.8	30	0.35	0.28	79	66.5	532		8.0	2.7
1640	0.34	28.0	85	380	26.6	14.8	30	0.36	0.28	79	67	532		0	0.2
1645	0.33	25.9	69	380	24.7	13.7	30	0.36	0.28	79	67	532		14.0	1.9
1651	0.33	23.0	67	377	20.5	13.0	30	0.36	0.28	79	67	533	8.0		3.0
1658:30	Item 7 to position H.														
1705	0.40	28.8	59	380	24.1	15.8	30	0.36	0.28	79	67.5	535		11.0	3.0
1718	0.40	27.0	100	380	27.5	15.5	29	0.35	0.28	79.5	67.5	535		0	0.2
1722:10	Zeolite cycled to No. 2 desorber.														
1727	0.32	23.0	60	380	15.2	12.5	30	0.35	0.28	80	67.5	535		12.4	2.0
1737:20	Silica gel cycled to No. 1 desorber.														
1738	0.30	25.0	60	380	29.0	15.3	30	0.35	0.28	80	67.5	535	8.5		4.3
1744	0.36	28.0	58	380	29.0	15.7	30	0.36	0.28	80	67.5	535		13.0	3.2

(1) Orifice calibration of 19 May 1965.

(2) Orifice H104-F

(3) Orifice K105-F

(4) Orifice A108-F

(5) Orifice A109-F

Table 8.2-XII. Final 10-psia Thermal Desorption Test; CO₂ Volume vs. Time

TIME	CO ₂ VOLUME (percent)			TIME	CO ₂ VOLUME (percent)		
	ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM		ZEOLITE BED IN	ZEOLITE BED OUT	ACCUM
1355	0.58			1545	0.82		
1357	0.58			1548		0.44	
1416		0.26		1606	0.80		
1419	0.68			1609		0.33	
1422		0.26		1638	0.86		
1427	0.70			1640		0.33	
1429	0.71			1652			98.7
1433		0.40		1704	1.20		
1446	0.76			1706	0.92		
1447			99.1	1708	0.90		
1458		0.48		1711		0.34	
1500	0.80			1722	0.98		
1506		0.30		1725		0.58	
1532	0.86			1734	0.95		
1534		0.37		1739		0.38	
1536			98.5	1757			98.9

Process Air, Contd

Air specific heat 0.24 Btu/lb-°R

q rejected to process air (q_{ar}) - Btu/hr

$$q_{ar} = 61.4 (0.24) (114 - 53) = 900 \text{ Btu/hr}$$

Heating Fluid (DC-331)

Flow rate (W_{hf}) 193 lb/hr*

Fluid inlet temperature - 376°F

(Specific heat at 376°F = 0.442 Btu/lb-°R)

Fluid outlet temperature - 278°F

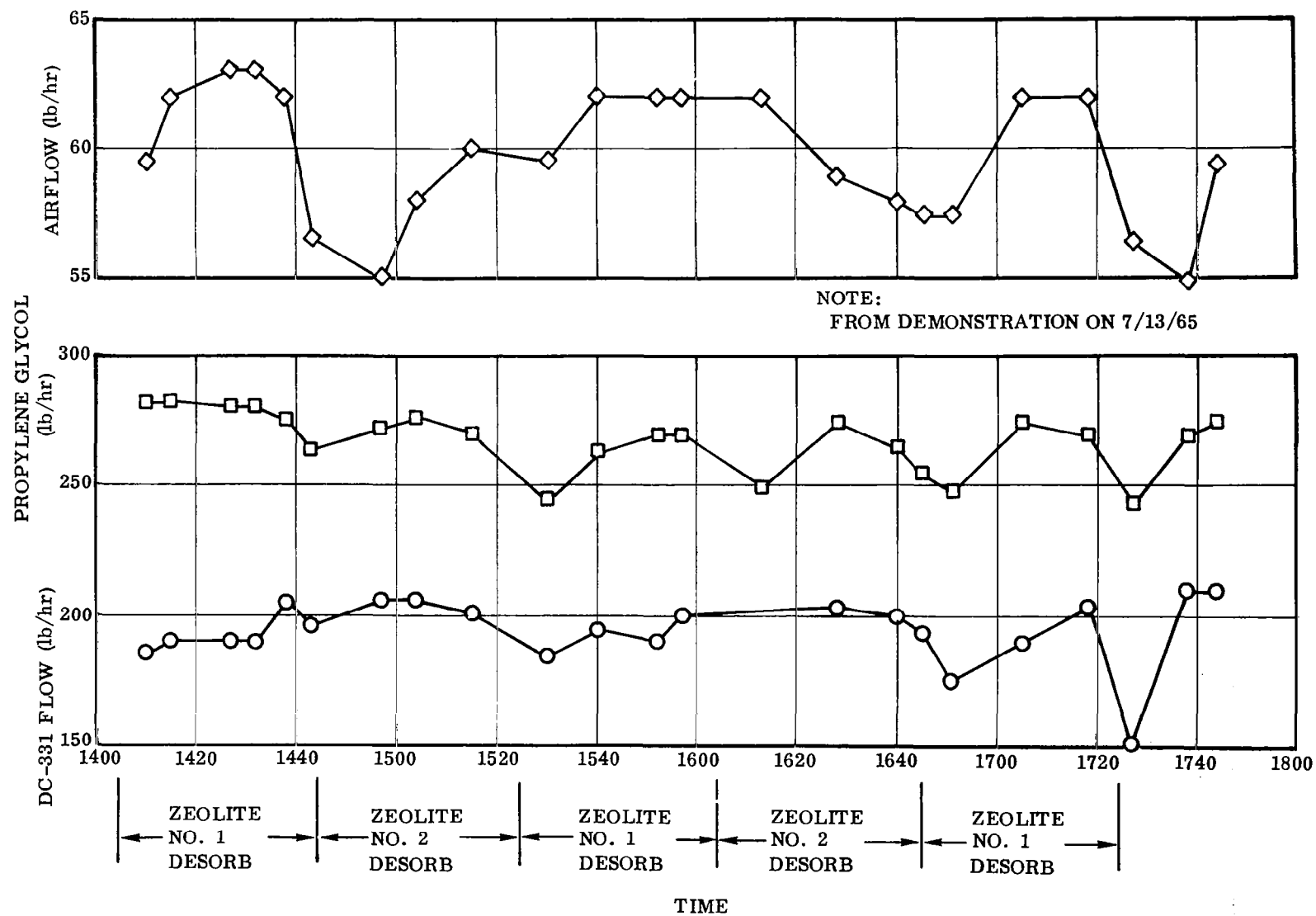
(Specific heat at 278°F = 0.415 Btu/lb-°R)

q rejected by heating fluid (q_{hr}) - Btu/hr

$$q_{hr} = 193 (0.442 \times 376 - 0.415 \times 278) = 8830 \text{ Btu/hr}$$

*The heating fluid flow rate was higher than desired because of a restriction in the balancing orifice of the waste management supply line. This restriction was found and eliminated after this test.

87-8

Figure 8.2-22. CO₂ Concentration Unit Thermal Desorption Mode Test

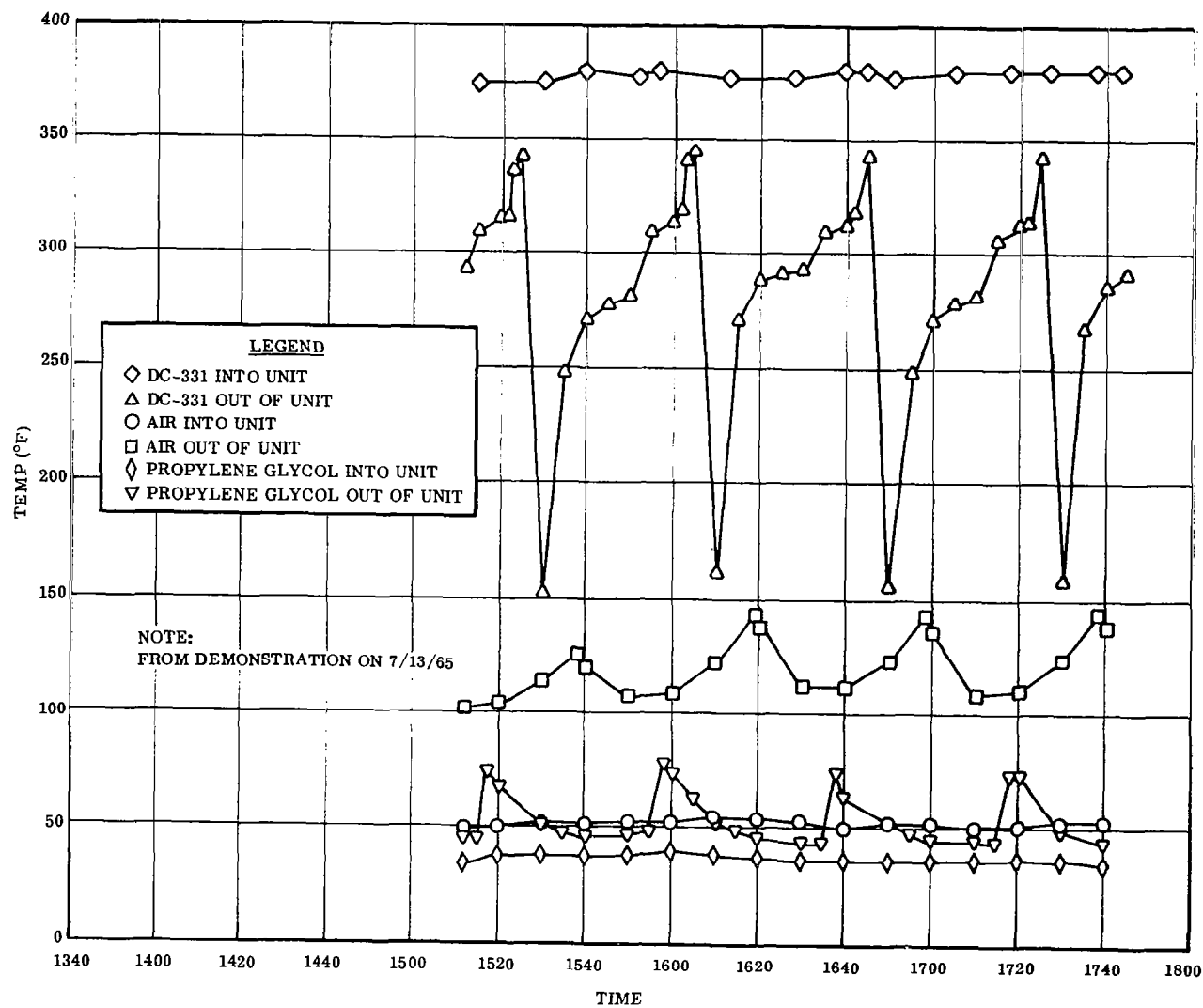


Figure 8.2-23. CO₂ Concentration Unit \approx 10 psia Thermal Desorption Mode Test Temperature

Cooling Fluid (42-percent propylene glycol)

Flow rate (W_{cf}) 260 lb/hr

Fluid inlet temperature - 37° F

Fluid outlet temperature - 55° F

Fluid specific heat - 0.894 Btu/lb-°R

q rejected to cooling fluid (q_{cr}) - Btu/hr

$$q_{cr} = 260 (0.894) (55 - 37) = 4180 \text{ Btu/hr}$$

From the above, it appears that 3750 Btu/hr was rejected directly to the atmosphere by conduction and radiation as the hot fluid heated elements of the system.

CO₂ Adsorption

CO₂ concentration in laboratory - 0.83 percent volume

CO₂ concentration out of adsorbing canister - 0.39 percent volume

The CO₂ removal efficiency (η_r) was $\frac{0.83 - 0.39}{0.83} (100) = 53$ percent

Volume flow of air (Q_a) = $W_a / 0.075 \sigma = \text{cfh}$

where

Standard air density at 14.7 psia and 70° F = 0.075 lb/ft³

$$\sigma = \text{actual density/standard density} = \frac{530}{513} \times \frac{530}{760} = 0.720$$

$$Q_a = 61.4 / 0.075 \times 0.720 = 1137 \text{ cfh}$$

$$W_{\text{CO}_2} = \frac{1137 \times 0.83 \times 0.53 \times 44}{359 (513/492) (100)} = 0.587 \text{ lb/hr}$$

From examination of accumulator pressure in Figure 8.2-24, it is seen that the CO₂ stored in the accumulator decreased at the rate of approximately 0.024 lb/hr. During this period, the reduction unit was operating at essentially the specification rate for a four-man crew or the equivalent of 0.387 lb CO₂ per hour. It would thus appear that the process rate of the concentration; unit was about 0.363 lb/hr. This would yield a cyclic efficiency of slightly less than 62 percent assuming the adsorbing and desorbing rates to be the same respectively for each canister.

The CO₂ concentration in the laboratory was an average of 4.4 mm Hg, as compared with the specification value of 3.8 mm Hg, which would probably tend to further decrease the unit process rate under specification conditions. Realizing these

18-8

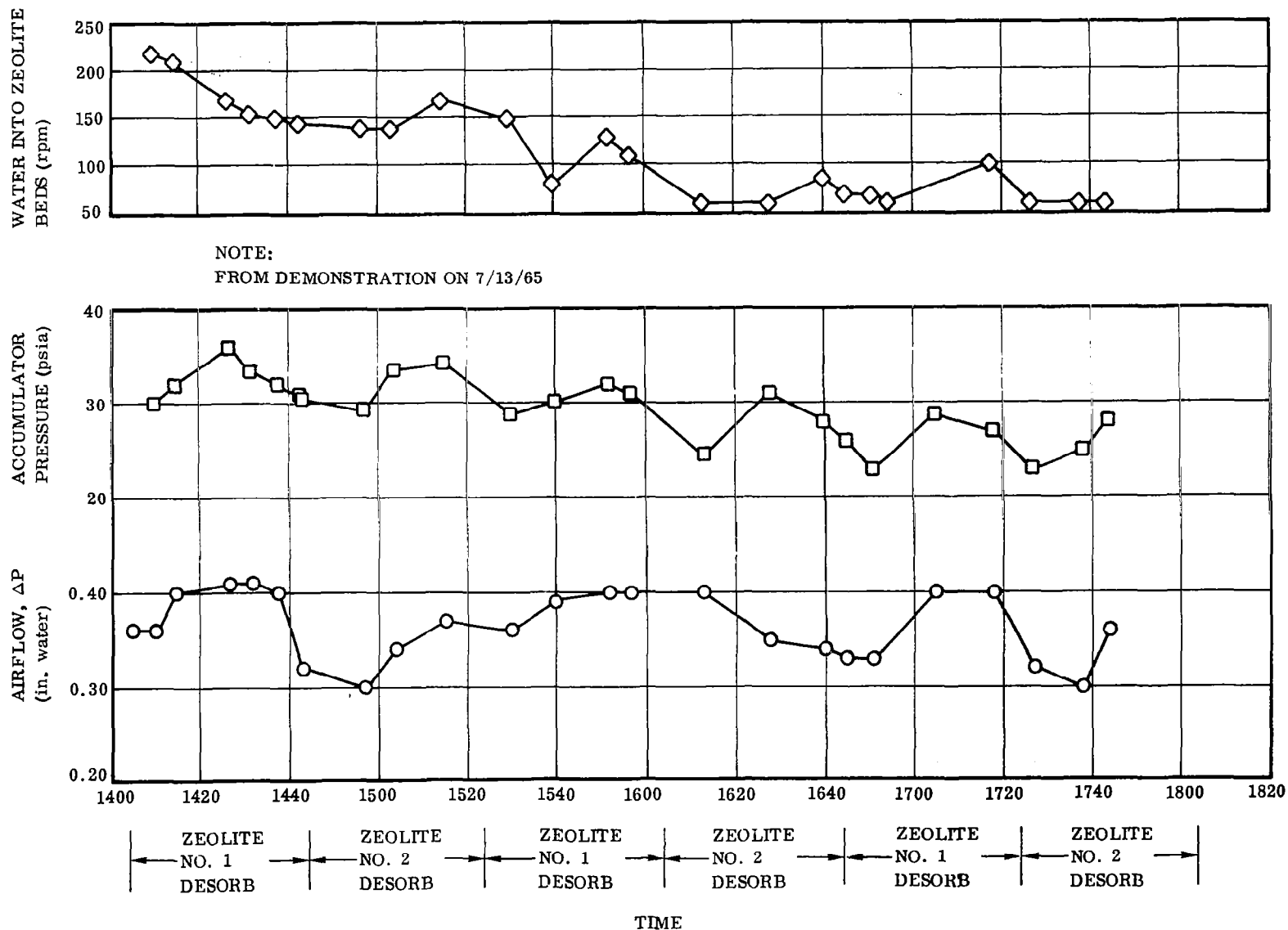


Figure 8.2-24. CO₂ Concentration Unit Demonstration Test

conditions to exist, it is obvious that the purge cycle of this unit must be carefully evaluated in further tests to determine if a more advantageous tradeoff may be obtained in purity of the accumulated CO₂ versus CO₂ process rate since nearly half of the CO₂ is presently being recycled in the purge after desorption in the bed.

Ten-psia Vacuum Desorption. Following a brief period of running at sea level to ascertain dryness of the silica gel beds, test of the unit at 10 psia in the vacuum-desorption mode was initiated. No difficulty was encountered in startup or unit operation except that water content of the process air leaving the silica gel bed appeared to be abnormally high. It has been noted in previous developmental runs that even though the beds are dried at sea level to less than 100 ppm, testing at 10 psia following such a drydown yields a water content that always starts high and reduces to a lower level as the test progresses. The reason for this has not been investigated at this time.

From an initially high CO₂ concentration in the test bed, concentration reduced to about 0.95 percent (volume) and remained constant throughout the test. The test was initiated at 1230 hours and continued until approximately 1430 hours, at which time it was agreed between the test conductor and the NASA representatives that an adequate demonstration had been obtained. Data recorded for these tests are presented in Tables 8.2-XIII and 8.2-XIV. The cyclic values of the system parameters shown in Figures 8.2-25 through 8.2-28 were essentially the same for this test as for the previous thermal-desorption mode test. The flow of DC-331 was approximately 25 lb/hr lower than the previous test because the foreign matter restricting the balancing orifice in the waste management supply line had been removed. This did little to affect temperature profiles as shown by comparing Figures 8.2-23 and 8.2-26. An apparent significant difference is shown in Figure 8.2-27 compared with Figure 8.2-29. Zeolite-bed adsorption in the vacuum-desorption mode appears to be significantly better than it was for the thermal-desorption mode. It may be that this actually occurred but it is more likely that this was the result of a difference in unit purge time and less frequent data accumulation. The purge time is approximately 8 minutes in the vacuum mode compared with 11 minutes in the thermal-desorption mode. The extra 3 minutes result in a very large amount of CO₂ being returned to the inlet to recycle through the unit. The laboratory concentration shown does not reflect the higher inlet concentration that actually exists for the longer purge and thus cannot be used as an absolute index of adsorption capacity when comparing the two modes of operation. Since laboratory CO₂ concentration remained essentially constant during test and a four-man crew was present throughout the test, capacity of the unit was thus equal to the CO₂ expiration rate of the four men. It would thus appear that unit performance is adequate for either the vacuum- or thermal-desorption mode.

Table 8.2-XIII. NASA 10-psi Demonstration Vacuum Desorption Run Test Data

TIME	AIR FLOW ⁽¹⁾ ΔP (in. H ₂ O)	P _{accum} (psia)	H ₂ O (ppm)	DC-331	DC-331	GLYCOL	SYSTEM A	LABORATORY	LIVING	T _{lab} (°F)	T _{living} (°F)	P _{cabin} (mm Hg)	WATER FROM SEPA- RATOR DUCT			
				T _{in} (°F)	FLOW ⁽²⁾ ΔP (in. H ₂ O)	FLOW ⁽³⁾ ΔP (in. H ₂ O)	T _{hx-out} (°F)	AIR FLOW ⁽⁴⁾ ΔP (in. H ₂ O)	AIR FLOW ⁽⁵⁾ ΔP (in. H ₂ O)				R.H. (%)	W ₁ (gm)	W ₂ (gm)	P _{can} (mm Hg)
1235	Started cone unit for vacuum desorption tests.															
1238	0.40		500	375	17.0	11.0	32	0.23	0.24	66	64.0	520		2685	2650	
1253	0.46		340	375	14.5	10.5	32	0.22	0.24	66	64	520	60			0.8
1248:30	Zeolite cycled to No. 2 desorber.															
1259	0.38		340	375	18.0	12.8	32	0.22	0.24	66	64	520	60			200
1305	0.41		340	375	13.6	11.9	32	0.22	0.24	66	64	520	60			5.5
1314:15	Silica Gel cycled to No. 1 desorber.															
1320	0.40		145	375	20.3	10.0	32	0.22	0.24	65	64	520	59.5			0.85
1330	0.38		120	375	21.0	10.0	32	0.22	0.24	65	64	520	59.5			0.85
1338:40	Zeolite cycled to No. 1 desorber.															
1340	0.35		105	375	18.5	12.5	31	0.22	0.24	65	64	520	59.5			170
1352	0.33		90	375	14.0	10.5	31			65	64	521	59.5			0.95
1403	0.42		88	375	14.8	10.1	32	0.22	0.24	65	64	522	59.5			0.80
1417	0.40		100	375	20.2	12.1	32	0.22	0.24	65	64	522	60	3880	2695	1.9
1418:30	Zeolite cycled to No. 2 desorber.															
1428	0.35		90	375	17.0	11.0	32	0.22	0.24	65	64	523	59.5			3.1
1437	0.35		85	375	19.7	10.0	31	0.22	0.24	65	64	523	59			0.70
1440														4120	2710	

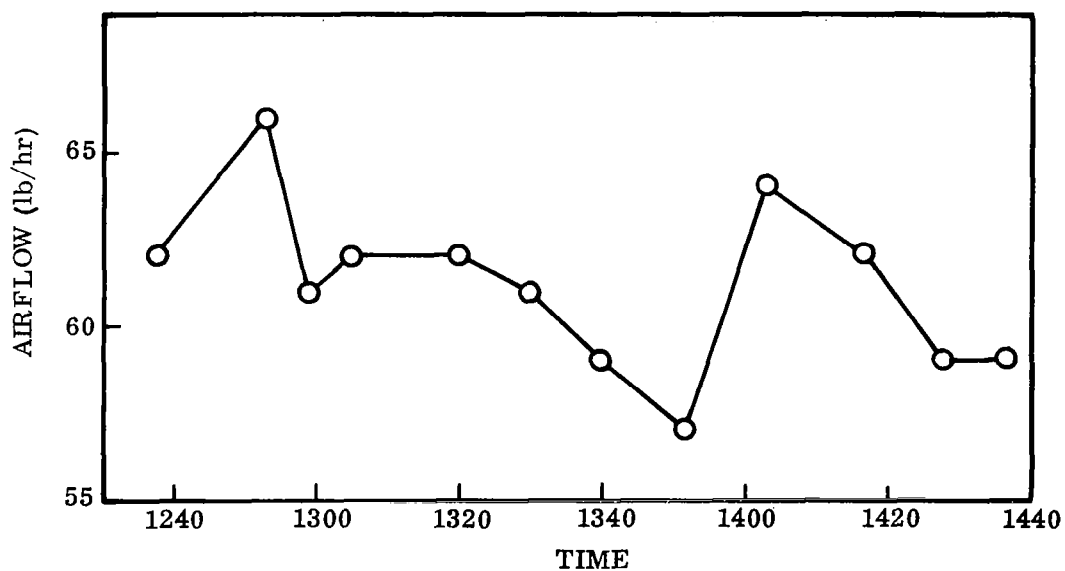
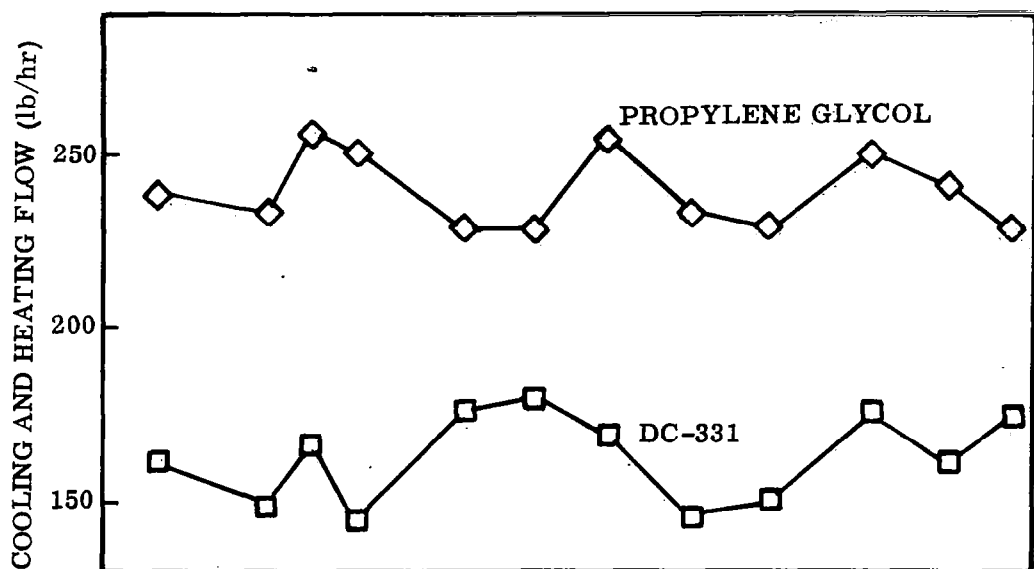
(1) Orifice calibration of 19 May 1965.

(2) Orifice H104-F

(3) Orifice K105-F

(4) Orifice A108-F

(5) Orifice A109-F



NOTES:

1. TEST BED PRESSURE \approx 10 PSIA
VACUUM DESORPTION
2. FROM DEMONSTRATION ON 7/15/65

Figure 8.2-25. CO_2 Concentration Unit Flow Rate

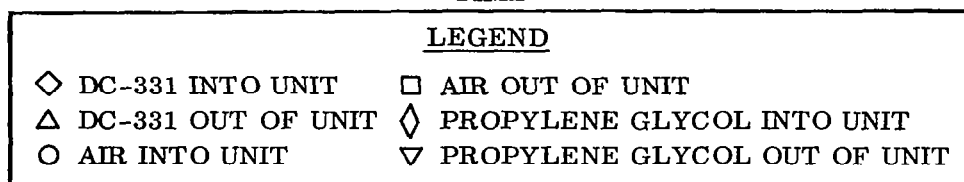
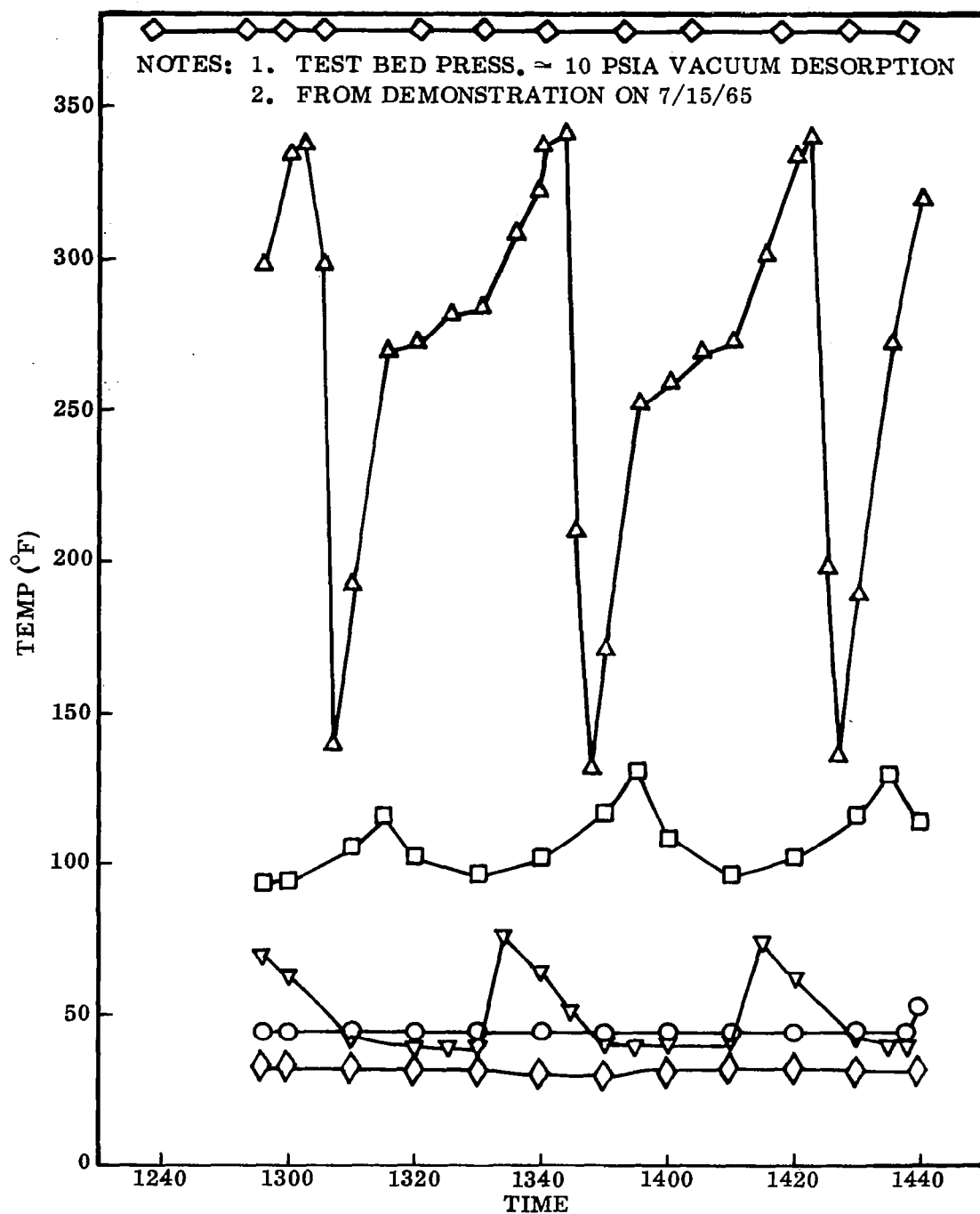


Figure 8.2-26. CO₂ Concentration Unit Temperatures

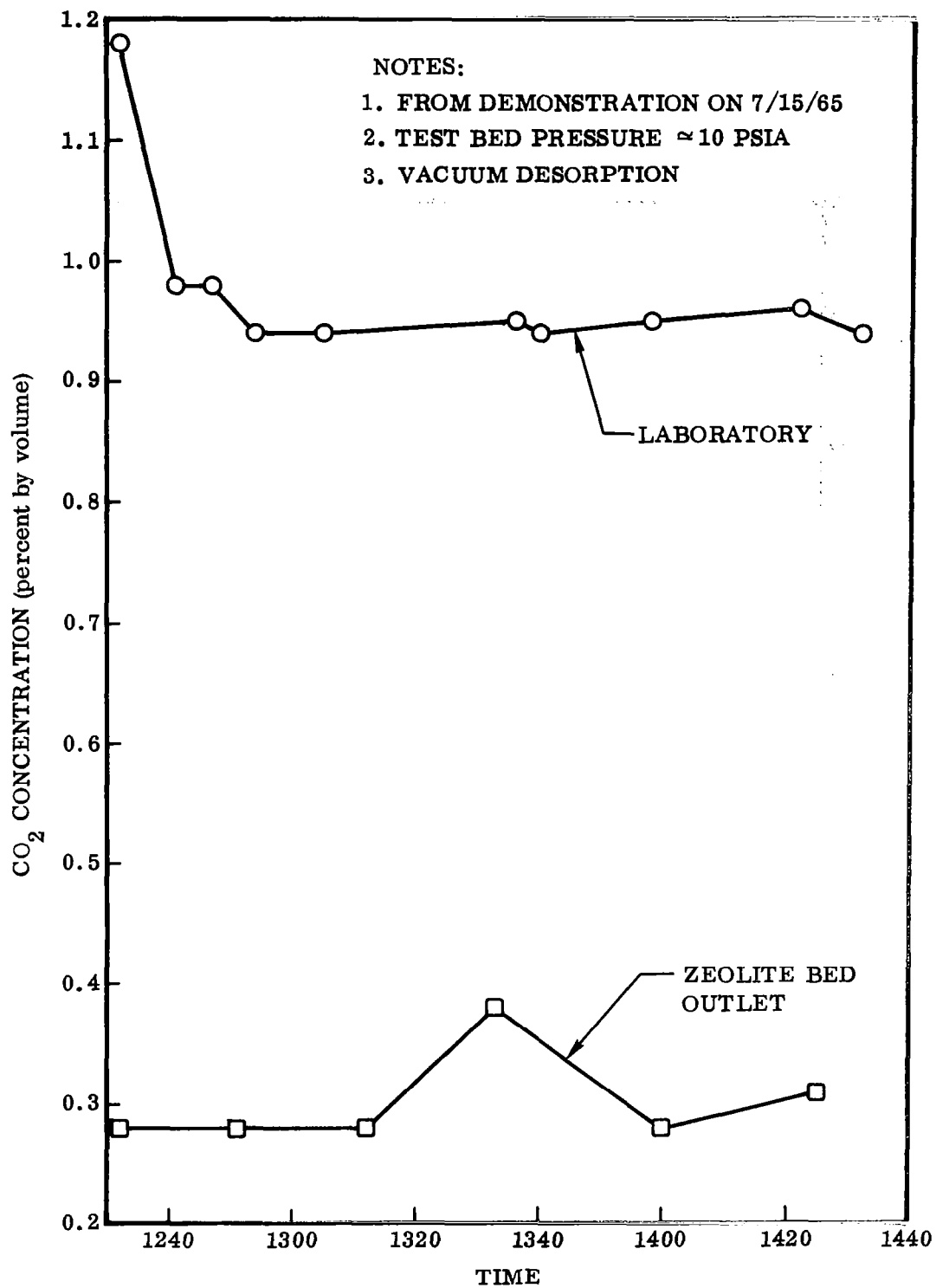


Figure 8.2-27. Cabin and Zeolite Bed CO₂ Concentration

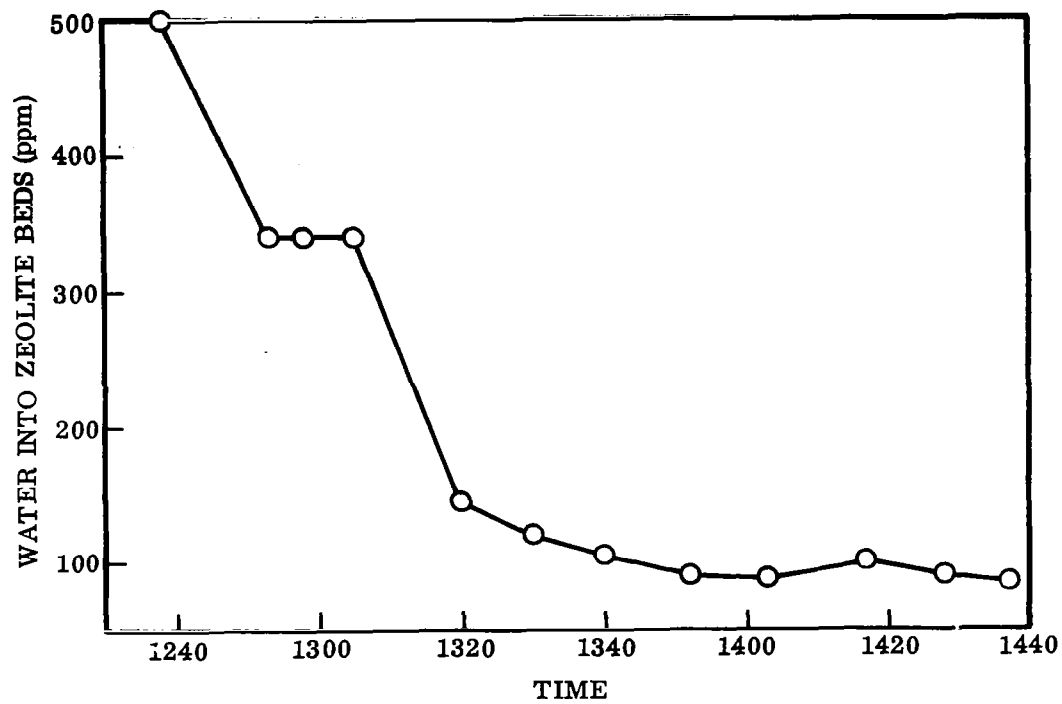


Figure 8.2-28. CO₂ Concentration Unit Moisture Content

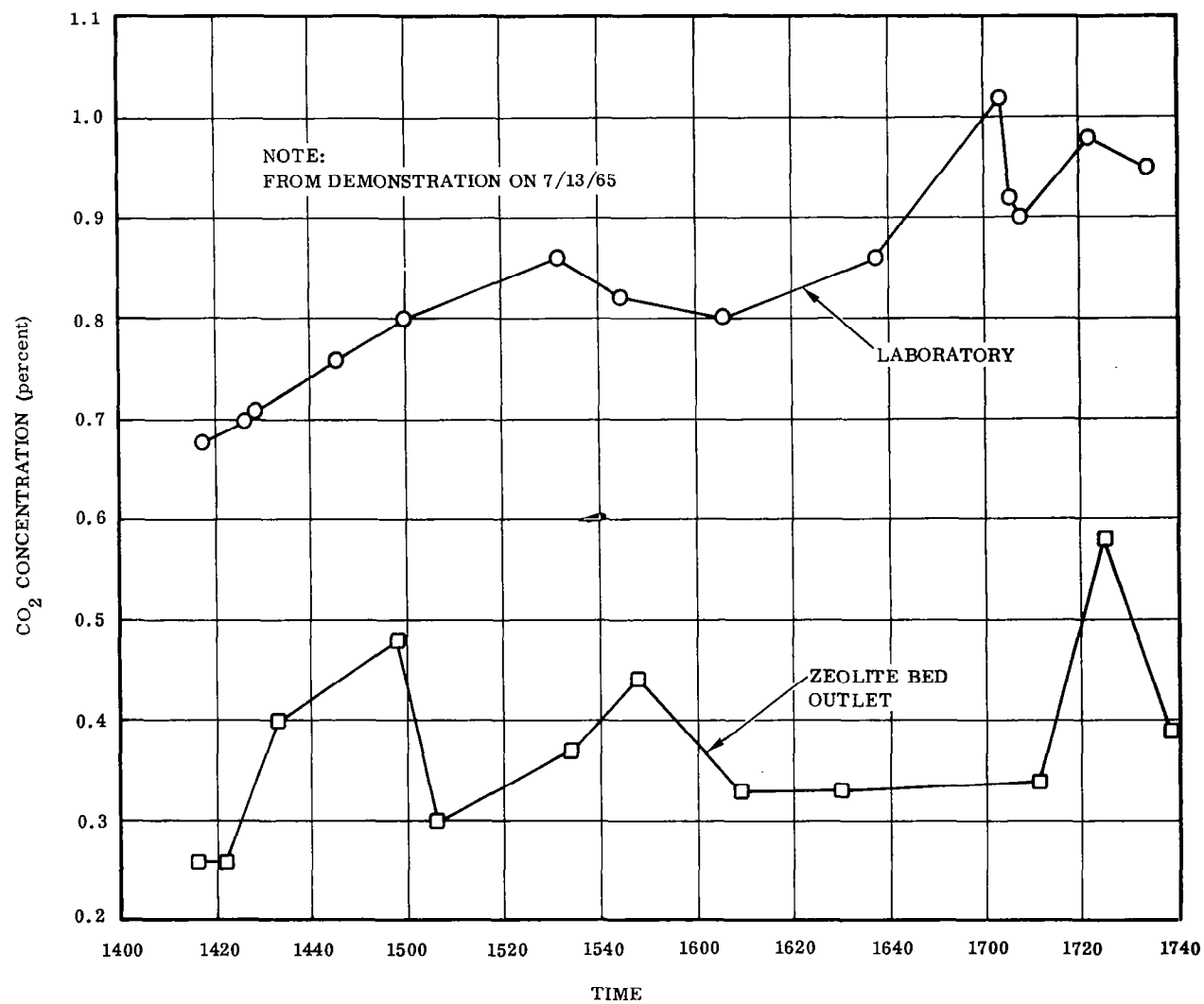


Figure 8.2-29. Laboratory and Zeolite Bed CO₂ Concentration

Table 8.2-XIV. Final 10-psia Vacuum Desorption Test; CO₂ Volume vs. Time

TIME	CO ₂ VOLUME (percent)		TIME	CO ₂ VOLUME (percent)	
	ZEOLITE BED IN	ZEOLITE BED OUT		ZEOLITE BED IN	ZEOLITE BED OUT
1224	1.90		1312		0.28
1226	1.50		1333		0.36
1229	1.30		1336	0.95	
1232	1.18		1340	0.94	
1241	0.98		1358	0.95	
1247	0.98		1400		0.28
1251		0.28	1422	0.96	
1254	0.94		1425		0.32
1305	0.94		1432	0.94	

8.2.2 CO₂ REDUCTION UNIT

8.2.2.1 SAI Tests. Source acceptance inspection (SAI) tests were conducted at the TRW facilities, Cleveland, Ohio, in November 1964. A test plan had been negotiated with TRW prior to the tests to establish the conditions, instrumentation, schedule, and duration of individual phases of the test.

The plan required one startup and demonstration of the maximum process rate and transient response to cyclic interruption of CO₂ feed flow. The CO₂ and H₂ feed pressure were to be set at constant values for steady-state operation and H₂ feed manually controlled by the mixture control valve. Nitrogen was to be added with the CO₂ and the percentage in the loop controlled by bleed to the catalytic burner. Feed gas would be supplied from commercial bottles of dry gas.

The unit was tested successfully in both operating modes, although the measured water rate was from 40 percent to 60 percent of the theoretical rate, even allowing for gas lost in purge, Tables 8.2-XV and 8.2-XVI. The low water catch could have been caused by an undetected feed-gas leak downstream of the flow element, leakage of product gas, or errors in the measured feed rate. The cause was not discovered in the SAI tests.

8.2.2.2 Convair Functional Checkout and Unit Evolution. Functional checkout testing was conducted in January 1965 to verify the installation and operation of the reduction unit in the test bed at Convair. (See Tables 8.2-XVII and 8.2-XVIII. Data acquisition was secondary to the basic purpose of the functional checkout, although 114 hours of test time were obtained during the 3-month period from 12 January to 14 April 1965. Of the total test time, 67 hours were utilized for warmup and hold and 47 hours were

Table 8.2-XV. Typical SAI Test Data*, CO₂ Reduction Unit, Bosch Mode

Time	1700	1800	1900	2000	2100
CO ₂ Feed Rate, lb/day	11.3	10.3	10.8	10.5	11.1
H ₂ Feed Rate, lb/day	0.945	0.895	0.935	0.830	0.875
Recycle Rate, cfm	2.85	2.80	3.00	2.95	3.00
Purge Rate, cfm	0.009	0.010	0.010	0.010	0.014
Water Separator Pressure, psig	1.50	1.60	1.25	1.20	1.25
Bosch Reactor Pressure, psig	4.2	6.0	4.9	7.3	7.1
Temperature, °F					
Bosch Reactor	1240	1238	1240	1238	1240
Carbon Collector	100	100	100	90	80
Water Separator	35.5	37.5	36.6	43.5	35.7
Compressor Discharge	145	150	150	150	150
Bosch Reactor Inlet	580	630	620	660	650
Bosch Reactor Power, watts					
Main Heater	720	720	720	720	720
Auxiliary Heater	0	0	0	0	0
Gas Analysis, volume %					
H ₂	64.0	54.0	52.0	50.0	50.0
CO ₂	5.8	5.8	5.7	6.5	6.0
CH ₄	17.4	22.0	22.4	22.6	19.0
CO	16.8	18.6	22.0	23.4	21.5
N ₂	6.0	3.0	3.5	2.0	3.2
O ₂	-	-	-	-	-
Water Rate, lb/day	-	5.85	5.00	4.55	4.45
Theoretical Water Rate, lb/day	-	7.56	7.95	6.98	7.19

*14.7 psia; 18 November 1964.

Table 8.2-XVI. Typical SAI Test Data*, CO₂ Reduction Unit, Sabatier Mode

Time	0300	0330	0400	0430	0500
CO ₂ Feed Rate, lb/day	8.77	9.05	9.43	9.64	9.56
H ₂ Feed Rate, lb/day	1.69	1.70	1.76	1.75	1.75
Sabatier Reactor Pressure, psig	2.0	1.9	2.0	1.8	1.8
Temperature, ° F					
Sabatier Reactor	370	370	405	465	460
Desulfurization Chamber	180	150	165	190	198
Water Separator	40.5	42.0	41.5	45.0	47.5
Gas Analysis, volume %					
H ₂	67.5	44.3	40.0	45.0	42.0
CO ₂	4.5	5.7	-	1.0	1.0
CH ₄	28.0	50.0	60.0	54.0	57.0
Water Rate, lb/day	4.88	4.88	4.88	5.28	5.28
Theoretical Water Rate, lb/day	7.18	7.40	7.70	7.86	7.83

*14.7 psia; 19 November 1964.

run at design conditions, including 29 in Bosch mode and 18 in Sabatier. An additional 6 hours were run at design conditions during the final demonstration tests in July.

The nature of functional checkout is best illustrated by the following chronological excerpts from the early phase of the checkout program.

- a. January 8, 1965. Internal Volume, Bosch Mode. The internal volume was determined by pressurizing the unit with CO₂ and measuring feed flow and the pressurization rate. The volume determined by this method is 1.21 ft³.
- b. January 8, 1965. Leakage Rate (Cold), Bosch Mode. The unit was purged and pressurized with He to 3.4 psig and the initial depressurization rate was measured. The calculated leakage rate at 3.2-psig internal pressure is 85 cc/min using the measured volume of 1.21 ft³.

Table 8.2-XVII. Typical Functional Checkout Data*, CO₂ Reduction Unit,
Bosch Mode

Time	1230	1430	1530	1600	1645
CO ₂ Feed Rate, lb/day	0.0	-	-	10.4	10.4
H ₂ Feed Rate, lb/day	0.0	-	-	0.965	0.965
Recycle Rate, cfm	1.5	-	-	3.0	3.0
Purge Rate, cfm	0.00	-	-	0.00	0.020
Water Separator Pressure, psig	1.20	-	-	1.20	1.20
Bosch Reactor Pressure, psig	4.4	-	-	3.0	3.0
Temperature, °F					
Bosch Reactor	980	-	-	1080	1080
Carbon Collector	-	-	-	-	-
Water Separator	36.0	-	-	39.0	39.0
Compressor Discharge	125	-	-	160	140
Bosch Reactor Inlet	300	-	-	480	530
Bosch Reactor Power, watts					
Main Heater	780	-	-	640	640
Auxiliary Heater	0	-	-	0	0
Gas Analysis, volume %					
H ₂	-	63.0	63.0	63.5	
CO ₂	-	11.0	11.0	10.5	
CH ₄	-	15.5	15.5	16.5	
CO	-	9.5	9.5	8.0	
N ₂	-	1.0	1.0	1.5	
O ₂ (ppm)	-	10 - 20	10 - 20	15 - 25	
Water Rate, lb/day	-	-	5.5	5.5	5.5
Theoretical Water Rate, lb/day	-	-	-	8.50	8.15

*14.7 psia; 12 January 1965.

Table 8.2-XVIII. Typical Functional Test Data*, CO₂ Reduction Unit,
Sabatier Mode

Time	1305	1340	1425	1505	1535
CO ₂ Feed Rate, lb/day	8.93	8.56	8.75	8.75	8.75
H ₂ Feed Rate, lb/day	1.63	1.63	1.63	1.63	1.63
Sabatier Reactor Pressure, psig	1.5	1.5	1.4	1.4	1.4
Temperature, °F					
Sabatier Reactor	540	535	555	520	525
Desulfurization Chamber	180	180	180	180	180
Water Separator	39.0	40.7	42.5	42.5	43.5
Gas Analysis, volume %					
H ₂	-	-	-	-	-
CO ₂	-	-	-	-	-
CH ₄	-	-	-	-	-
Water Rate, lb/day	4.3 average				
Theoretical Water Rate, lb/day	7.32	7.00	7.16	7.16	7.16

*14.7 psia, 14 January 1965.

c. January 11, 1965. Electrical and Fluid/Mechanical Checks.

1. A short circuit was discovered in 400-cps ac-Switch S-15 and repaired.
2. The Bosch main heater operated at half power. The leads were changed to apply full voltage and full power was obtained.
3. DC-331 Valve V-15 leaked at the valve stem and V-14 leaked badly at the same location. The valves were removed and the heating-fluid lines to the feed-gas heater were capped to permit continuation of functional checkout. The feed-gas heater is not essential to the operation of the unit, and the bypass provided by V-15 is redundant since there is a Convair bypass at the subsystem interface.

d. January 12, 1965. Manual Bosch Operation

1. Equilibrium at 1080°F was obtained 6 hours after startup and the water output was then collected for a timed run of 1-1/2 hours with the recycle vent closed. Feed-gas flow was set to a stoichiometric mixture using the laminar flow-element readouts. The corrected CO₂ flow was 10.4 lb/day and the H₂ flow was 0.96 lb/day, a weight-flow ratio of 10.9. The stoichiometric weight-flow ratio is 11.0.
2. Water collection was 157.5 grams, which corresponds to a water rate of 5.52 lb/day. Theoretical water production is 8.5 lb/day based on the measured feed flow with no bleed and no leakage.
3. Analyses of gas samples taken upstream of the reactor did not vary significantly during the test run:

$$H/O = 6.6$$

<u>Gas</u>	<u>Composition by Volume, Percent</u>
H ₂	63.5
CH ₄	16.5
CO ₂	10.5
CO	8.0
N ₂	1.5

4. The discrepancy between theoretical water production and the actual water catch cannot be accounted for by gas leakage. Hot-leakage tests made with hydrogen, January 23, 1965, indicate 475 standard cc/min between Valves V-7 and V-12. Cold leakage tests made with hydrogen, January 25, 1965 indicate 376 standard cc/min between the feed-gas valves and V-7. A mass balance was attempted by the following procedure.

- (a) Assigned the gas composition obtained by analysis to the leakage measured upstream of V-7 (376 standard cc/min):

<u>Gas</u>	<u>Leakage</u> <u>Standard cc/min</u>	<u>Pounds/day</u>
H ₂	240	0.068
CH ₄	62	0.140
CO ₂	40	0.250
CO	30	0.120
N ₂	5.6	0.022

- (b) The hydrogen loss is the sum of the free-hydrogen leakage, the hydrogen lost in methane leakage, and an additional amount of hydrogen to form leak-replacement methane (methane concentration was constant at the sample port). Hydrogen available for water production is then $0.96 - (0.068 + 0.035 + 0.035) = 0.822$ lb/day and water production would be 7.39 lb/day.
- (c) The CO_2 loss is the direct leakage plus the CO_2 required to provide the oxygen lost in CO leakage, and an additional amount of CO_2 to form leak replacement CO. (The CO concentration was constant at the sample port.) The available CO_2 is then $10.4 - (0.250 + 0.094 + 0.094) = 9.962$ lb/day.
- (d) The gas flow out of the reactor based on hydrogen availability would be:

<u>Gas</u>	<u>Flow</u> <u>Pounds/day</u>	<u>Composition</u> <u>Percent by volume</u>
H_2	2.03	50.0
CO_2	0.91	1.0
CH_4	5.96	18.1
CO	5.05	8.8
H_2O	7.39	20.0
N_2	0.95	1.6

- (e) If we assign this composition to the leakage measured for the hot package (475 standard cc/min) the water vapor leakage is 192 cc/min of 0.48 lb/day. The maximum possible water catch would be 6.91 lb/day, which is 81 percent of the theoretical water production based on measured feed-gas flow with no bleed or leakage (the measured water catch is 65 percent of theoretical water production).

e. January 13, 1965. Manual Sabatier Operation

1. Reaction was initiated 2 hours after startup at a reactor temperature of 410°F. Attempts to initiate reaction at 340°F were unsuccessful and it was necessary to increase the delivery temperature of the heating/pumping unit to obtain a higher reactor temperature. The fluid temperature was reset to the normal value for the remainder of the test. Reactor temperature during the attempted starts was approximately 70°F below the fluid-delivery temperature of the heating/pumping unit.

2. Feed-gas flow was set to a 15-percent hydrogen-rich mixture using the laminar flow-element readouts. The corrected CO₂ flow was 4.55 lb/day and the hydrogen flow was 0.96 lb/day, a flow ratio of 4.75. The stoichiometric flow ratio is 5.5.
 3. The automatic temperature control was not energized and the reactor temperature appeared to stabilize at approximately 515° F with no cooling. The test was concluded with a timed run of 1-1/4 hours, yielding a water catch of 43 grams which is 49 percent of the theoretical water production based on CO₂ feed flow.
 4. There were no provisions for sampling vent gases for analysis.
 5. Repair and calibration of Bosch associated equipment was accomplished during the Sabatier test. Valves V-14 and V-15 were permanently removed, and the water-pump drive was removed to repair the coupling. The carbon-collection bag was inspected for evidence of overtemperature and found to be in excellent condition. The set point of the overtemperature light was determined to be 51° C (124° F). The bag contained very little carbon and was reinstalled.
 6. The DC-331 discharge temperature from the reactor did not read out on the pyrometer.
- f. January 14, 1965. Manual Sabatier Operation
1. Reaction was initiated 2 hours after startup at a reactor temperature of 360° F, obtained by temporarily increasing the fluid delivery temperature of the heating/pumping unit.
 2. Feed-gas flow was set to a stoichiometric mixture using the laminar flow-element readouts. The CO₂ flow was 8.75 lb/day and the hydrogen flow 1.6 lb/day, a mixture ratio of 5.5.
 3. Attempts to operate without cooling were unsuccessful; reactor temperature increased continuously, and the reactor high temperature light came on at 580° F. When the Dow-331 meter valve V-17 was opened ever so little, the reactor temperature decreased continuously.
 4. Stable operation was achieved with the automatic temperature control, using a set point of 525° F and V-17 slightly opened. The control band was $\pm 5^{\circ}$ F, cooling tanking place in 1-1/2 minutes and heating in 6 minutes. Reactor temperature on the pyrometer (T-12) was 370° F, later found to be out of calibration. DC-331 temperature out of the reactor (T-11) was 620° F, approximately 100° F above the reactor set point.
 5. The water catch in 3-1/4 hours was 265 grams, which is 60 percent of the theoretical water production.

6. Analysis of Sabatier vent gas periodically diverted to the analyses apparatus through a temporary line showed 21 percent N_2 , indicating air leak in the line. The gas sample ports have since been relocated upstream of Valve V-7 so that reliable gas samples may be obtained in either Bosch or Sabatier mode.
7. The DC-331 bypass valve seats are teflon, which deforms permanently at elevated temperature and causes internal and external leakage. The valves were replaced with all-metal valves.
- g. January 21, 1965. Precooler Leakage. FC-75 was found in the precooler and recycle line, and inspection revealed that the precooler was leaking internally and externally. All lines were flushed with isopropyl alcohol to remove the FC-75 and the precooler was disconnected from the FC-75 circuit. The gas leak was temporarily patched with dental cement.
- h. January 23, 1965. Hot leakage Test
 1. A Sabatier test was attempted to accomplish automatic mixture control and low-temperature runs but was aborted due to difficulties with DC-331 bypass valves and the heating/pumping unit.
 2. The reduction unit was purged with hydrogen in the Bosch mode and brought up to $1100^\circ F$ for leakage tests at operating temperature. The feed gas heater was $250^\circ F$. The following results were obtained.

Volume

Low-temperature package	0.16 ft ³
High-temperature package	<u>1.05 ft³</u>
Total	1.21 ft ³

Leakage (at 3.2 psig, corrected to standard density)

Total

Recycle compressor off 765 cc/min

Recycle compressor on 570 cc/min

High-temperature package 475 cc/min

Low-temperature package 162 cc/min

- i. January 25, 1965. Cold Leakage Test. High leakage was verified by cold leakage tests using hydrogen.

Leakage (at 3.2 psig, corrected to standard density)

Total

Recycle compressor off 720 cc/min

Recycle compressor on 610 cc/min

High-temperature package 156 cc/min

Low-temperature package 376 cc/min

- j. January 25, 1965. Calibration of Laminar-Flow Elements. External Brooks rotometers were used to check the readouts of the laminar-flow elements and found to be in agreement.
- k. January 26, 1965. Removal from Test Bed. The reduction unit was removed from the test bed, stripped of insulation, and cleaned for inspection.
- l. January 27, 1965. Inspection
 - 1. The fiberglass shields for the drive motor and filter-selector valves were burnt in those areas closest to the reactor, indicating that the odor during the Bosch tests was caused by the fiberglass binder.
 - 2. The Bosch reactor drive pin was found to be missing when the drive was lifted from the reactor, and the drive shaft could not be rotated.
 - 3. The reactor was disassembled and photographed. Scraping action was found to be impossible due to mechanical binding of the rotating assembly. The upper catalyst plates were severely warped and the majority of the plates were loose on the shaft.

8.2.2.3 Final Demonstration Tests. Final evaluation of the reduction unit was accomplished at Convair during the integrated demonstration tests for NASA/LRC.

Bosch Test, 13 July 1965. The reduction unit was brought up to temperature with the electric heaters and operated in the Bosch mode at sea-level pressure prior to testing at 10 psia. About 12 hours leadtime was required for warmup, using 600 watts on the auxiliary heaters and a main heater power level that was gradually reduced from 500 watts to 200 watts as the reactor came up to temperature (See Table 8.2-XIX.)

Discussion. Reaction was initiated with feed gas from storage bottles, then transferred to feed from the electrolysis and concentration units. The unit was then shut down and left unattended during pump-down and preparation of the 10 psia environment. No difficulty was encountered in restarting the reaction at 10 psia, although reactor temperature had dropped about 90° F during shutdown. The reaction rate increased as the reactor came up to the temperature set point of 1240° F. Stable

**Table 8.2-XIX. Typical Demonstration Test Data*, CO₂ Reduction Unit,
Bosch Mode**

Time	1535	1600	1630	1700	1730
CO ₂ Feed Rate, lb/day	9.7	10.2	10.8	11.2	11.1
H ₂ Feed Rate, lb/day	0.900	0.960	1.02	1.02	1.02
Recycle Rate, cfm	2.25	2.25	2.25	2.25	2.25
Purge Rate, cfm	0.005	0.005	0.005	0.005	0.005
Water Separator Pressure, psig	2.20	2.18	2.10	2.00	1.95
Bosch Reactor Pressure, psig	9.6	9.3	9.2	9.1	8.9
Temperature, ° F					
Bosch Reactor	1230	1240	1240	1240	1240
Carbon Collector	115	115	120	125	125
Water Separator	47.3	47.0	46.0	44.7	44.0
Compressor Discharge	150	150	150	150	148
Bosch Reactor Inlet	800	810	820	820	820
Bosch Reactor Power, watts					
Main Heater	200	200	200	200	200
Auxiliary Heater	610	610	320	320	620
Gas Analysis, volume %					
H ₂	43.0	69.4	-	56.0	-
CO ₂	11.7	6.4	-	9.8	-
CH ₄	12.0	5.7	-	13.0	-
CO	12.0	6.0	-	11.0	-
N ₂	18.0	11.0	-	9.2	-
O ₂	3.0	1.5	-	0.7	-
Water Rate, lb/day	5.8	5.8	5.8	7.2	7.4
Theoretical Water Rate, lb/day	7.91	8.31	8.88	8.94	8.94

*10 psia; 13 July 1965.

operation was maintained until shutdown, 3-1/2 hours after restart at the 10-psia condition. The temperature control maintained set point temperature very closely; the auxiliary heaters were on full power approximately 90 percent of the time and half power for the remainder.

Test Results. It was necessary to use all of the H₂ output of the electrolysis unit to obtain a four-man-level water catch from the reduction unit so that feed-gas consumption appeared to exceed the water-production rate. A post-test check of the mixture-control package revealed a hydrogen leak that accounted for the high feed-gas requirement observed during the test.

The final configuration of the regenerative heat exchanger, without fins, performed as intended. About 75 percent of the heat in the reactor-discharge gases was recovered, while carbon was permitted to pass on to the collection bag in the canister. Maximum bag temperature was 125°F. Thirteen ounces of dry carbon were found in the bag after the test, which would correspond to 7 hours operation at the design rate. It is evident that some of the carbon collected is from previous test time on the reactor.

Gas leakage in the Bosch mode was 45 cc/min prior to the demonstration test, but was reduced to 7.6 cc/min after the test by inserting a new O-ring in the carbon collection canister.

The Bosch-mode demonstration test has verified the integrity, stability, and process rate of the primary operational mode of the unit at sea level and at 10 psia, and its compatibility with the oxygen regeneration system.

Sabatier Test, 15 July 1965. The reduction unit was brought up to temperature with DC-331 heating fluid and operated in the Sabatier mode at sea-level pressure prior to testing at 10 psia. A low reaction rate was initiated about 1 hour after the DC-331 was turned on, and the heat of reaction was then retained in the reactor by closing the DC-331 valve until the desired operating temperature was approached. Full process rate at 480°F was obtained about 1-1/2 hours after feed gas was first admitted to the unit. (See Table 8.2-XX.)

Discussion. The unit was not shut down during transition from sea-level pressure to the 10-psia test condition, but was left unattended at a 485°F set point. The unit was operating at the set point when the cabin was reoccupied 1 hour later, and continued at this temperature until the set point was changed to 500°F. The increase in temperature appeared to reduce the amount of unreacted hydrogen in the vent gas, although the water production rate remained 1 cc/min throughout the 10-psia test, which is normal for the feed rate used.

Feed gas was supplied from storage bottles throughout the test. The electrolysis unit was not used, and the CO₂ concentration unit was desorbing to vacuum.

Table 8.2-XX. Typical Demonstration Test Data*, CO₂ Reduction Unit,
Sabatier Mode

Time	1230	1300	1330	1400	1430
CO ₂ Feed Rate, lb/day	5.17	5.17	4.93	4.96	5.16
H ₂ Feed Rate, lb/day	1.01	1.04	0.891	0.980	1.01
Sabatier Reactor Pressure, psig	1.75	1.80	1.55	1.80	1.80
Temperature, ° F					
Sabatier Reactor	485	483	482	500	500
Desulfurization Chamber	165	165	170	170	170
Water Separator	-	-	-	-	-
Gas Analysis, volume %					
H ₂	-	30.8	-	5.6	-
CO ₂	-	10.7	-	10.4	-
CH ₄	-	56.0	-	84.0	-
Water Rate, lb/day	-	3.17 average			
Theoretical Water Rate, lb/day	4.23	4.23	4.03	4.06	4.22

*10 psia; 15 July 1965.

Test Results. Gas leakage in the Sabatier mode was 1.4 cc/min. The Sabatier mode demonstration test has verified the integrity, stability and process rate of the backup mode of the unit at sea level and at 10 psia.

8.2.3 ELECTROLYSIS UNIT

8.2.3.1 Preliminary Six-Cell Tests. A test electrolysis stack consisting of 6 cells was run at GE during the unit design phase of the program. It was intended to help evaluate extended operational performance and basic design of the cells. The stack was run in the laboratory and flow, current, voltage, pressure, and temperature were monitored. Other parameters, such as cell coolant-flow characteristics, liquid content of the output gases, and cell polarity reversal were also checked. A summary of the testing and results, as reported by GE, is given in the following paragraphs.

Operation of the test stack was initiated on 15 May 1965 and provided information that led to several design changes. For example, the seepage of H_2SO_4 through the membranes was not expected in the quantities experienced through the test-stack membranes. This observation led to the installation of the porous-plate gas-liquid separators to remove the liquid carried from the cells in the gas stream. The use of plexiglas electrolyte spacers resulted in a great deal of electrolyte leakage and difficult sealing problems. A spacer made of rubber was tried on a single cell with the result that no leakage was observed in a period of over 1 month. Therefore, molded-rubber spacers were used in the overall unit design.

During continuous operation for 8 days, none of the acid lost by the electrolyte pocket into the gas streams was replaced. The acid concentration in the electrolyte pocket during this time dropped from 25 percent to 10 percent, and yet the average cell voltage during this time was stable between 1.90 and 1.92 volts/cell. In addition to the variation in electrolyte concentration, the cell temperature during this time varied between about 95° F to 125° F and the rate of permeation of liquid through the membranes was found to increase by a factor of approximately 11.

After about 425 hours of operation, 1 cell was removed from the stack to evaluate the effects of the acid on the titanium-palladium current carriers. The discoloration noted at this time was compared with that observed on another cell that failed when the current polarity was reversed after several hundred additional hours of operation. The discoloration observed on the second plate was similar in all respects to that previously noted, and it was concluded that this discoloration resulted from starting the unit without sufficient purging, causing the oxygen in the air to burn with the hydrogen produced by the cell in the presence of the catalyst, platinum.

A test was performed to determine the amount of liquid that would permeate through the membrane if the electrolysis unit was not operating. The test indicated that no permeation should be expected even with a positive pressure on the liquid side. The test was conducted over a period of about 1 week.

Platinum black was observed in the electrolyte that was expelled from the gas pockets, and it coated the surface of the electrolyte spacer inside the cell. A material analysis was performed to verify that the coating was in fact platinum. No detrimental effects were observed from this phenomenon during testing.

Cell voltages increased during the period between 50 and 750 hours of operation from about 1.85 volts to 1.92 volts. During the first 50 hours of operation the voltages increased from 1.65 volts to 1.85 volts. At 750 hours of operation the polarity of the current to the test stack (5 cells) was reversed to evaluate the effects of this action. At this time the first cell burnout was observed and the voltage drops across each cell increased rather sharply -- stabilizing at an average of about 1.97 volts/cell. It was felt that this increase was due to a fire occurring in each cell caused by oxygen

entrapped in the membranes not being removed by the N₂ purge and combining with oxygen and burning on the platinum surface. The GE personnel experienced in fuel-cell operation stated that this could have occurred and would have resulted in an increase in voltages across the cells.

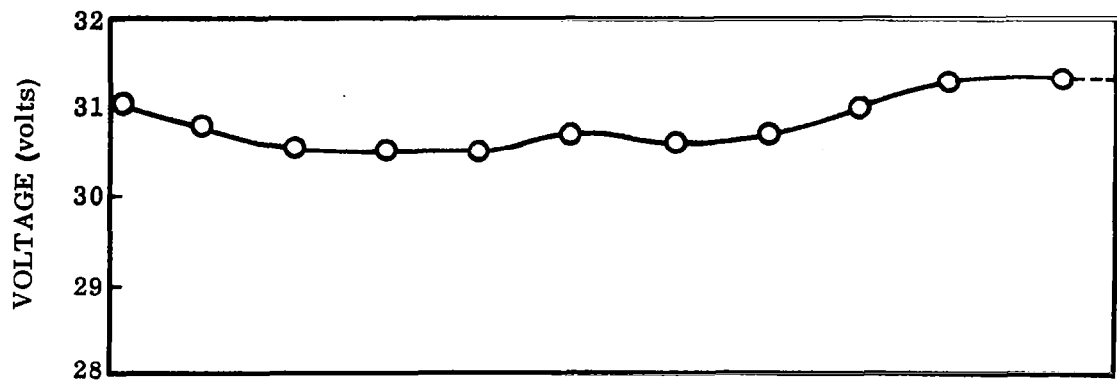
Following the polarity reversal, 3 cells were tested further for a total of 1190 hours. At this time, the level of the electrolyte in the test stack was accidentally permitted to fall below the point at which the cells were full. This resulted in a fire in the stack and severe damage to two of the cells. Following this fire, the test was terminated.

8.2.3.2 SAI Tests. The source acceptance inspection (SAI) test of the prototype water electrolysis unit was initiated on 19 November 1964. The test was to be performed in accordance with the test plan submitted to Convair. Some of the parameters measured during SAI testing are shown in Figures 8.2-30 through 8.2-32.

During the SAI testing after about 16 hours of operation, several cell voltages increased rapidly indicating possible membrane degradation. The unit was shut down, the modules were disassembled and examined, and the data were reviewed to determine the cause of the degradation. The rate at which the cells were degrading had not been experienced during the testing of the six-cell stack and, therefore, no positive cause for the difficulty could be determined -- although the operating temperature (140-145° F) and the differential pressure (2-2.5 psi) were suspected. Examination of the cells of the unit showed that the membranes had separated from the catalyst, thereby increasing the resistance of the membrane current-carrier assembly. Approximately 70 percent of the membranes showed signs of separation with damage to the oxygen membranes being more severe.

Upon determining the extent of the damage to the unit the SAI test was terminated, and a meeting was held at General Electric Direct Energy Conversion Operation (D. E. C. O.) to determine the cause of the membrane separation. The D. E. C. O personnel suggested that the failures were probably caused by the 140-145° F operating temperature. They did not discount the possibility of the operating pressure causing the failure although it did not appear likely to them.

As a result of the meeting the decision was made to build a new stack composed of the undamaged membranes, and to operate this rebuilt stack at 90-95° F and a differential pressure of between 1.5 and 2.0 psi to determine if the integrity of the unit could be maintained at these conditions. The unit with the single module was run for approximately 49 hours when the test was terminated at the request of Convair. Some of the operating parameters measured during this test are shown in Figure 8.2-33. Post-test inspection showed that no observable deterioration had occurred. The unit was then reassembled and operated for several more hours to certify proper operation following reassembly. Upon completion of this testing the unit with the rebuilt module was shipped to Convair. The other two modules were to be rebuilt, bench tested at GE, and later shipped to Convair.



NOTE:
MODULE OPERATED FOR 26.5 HR
PRIOR TO TEST

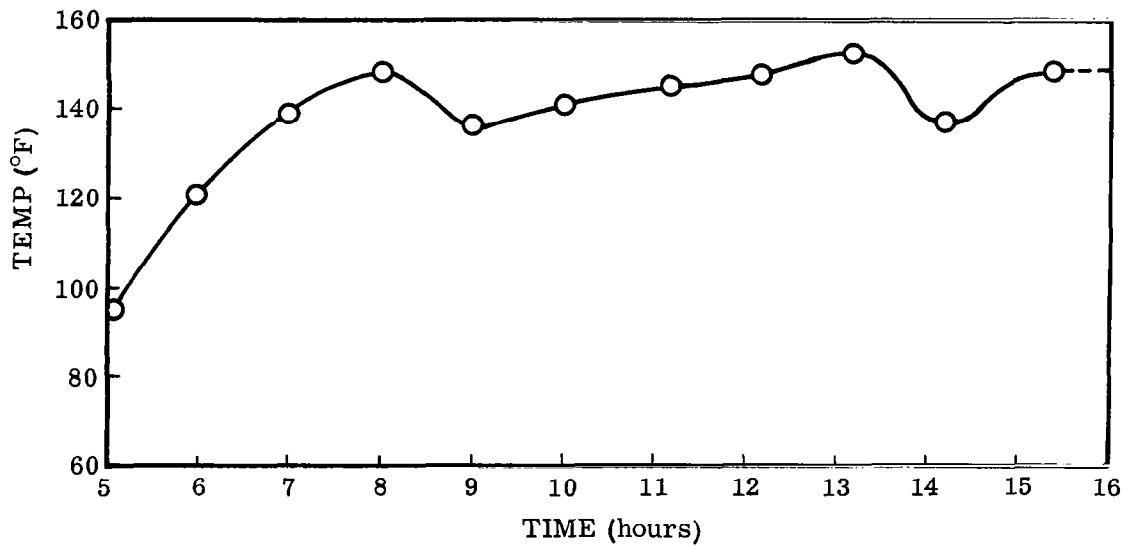
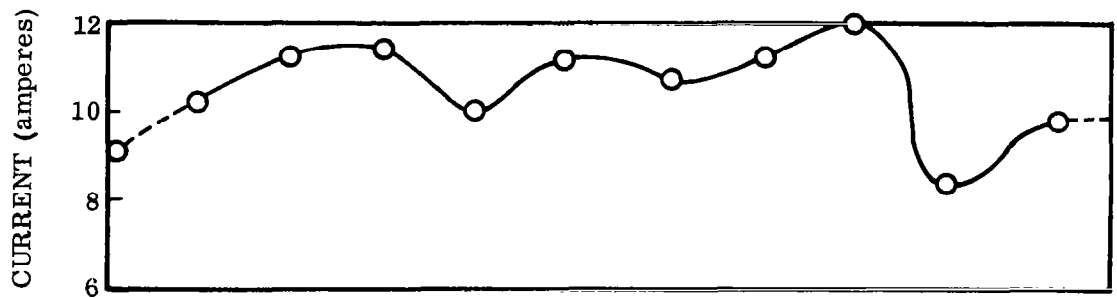
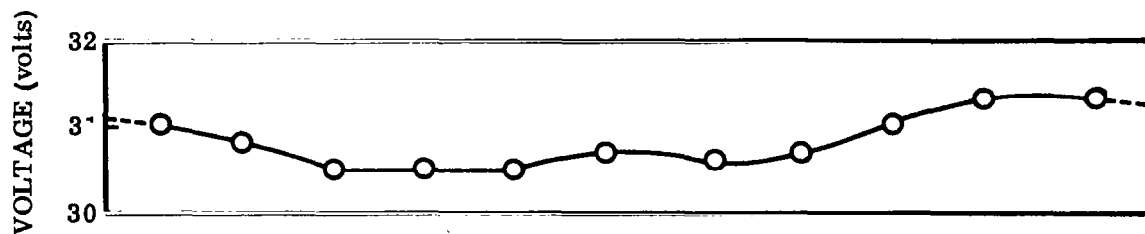


Figure 8.2-30. SAI Test Data, Electrolysis Module A



NOTE: MODULE OPERATED FOR 19.8 HR
PRIOR TO TEST

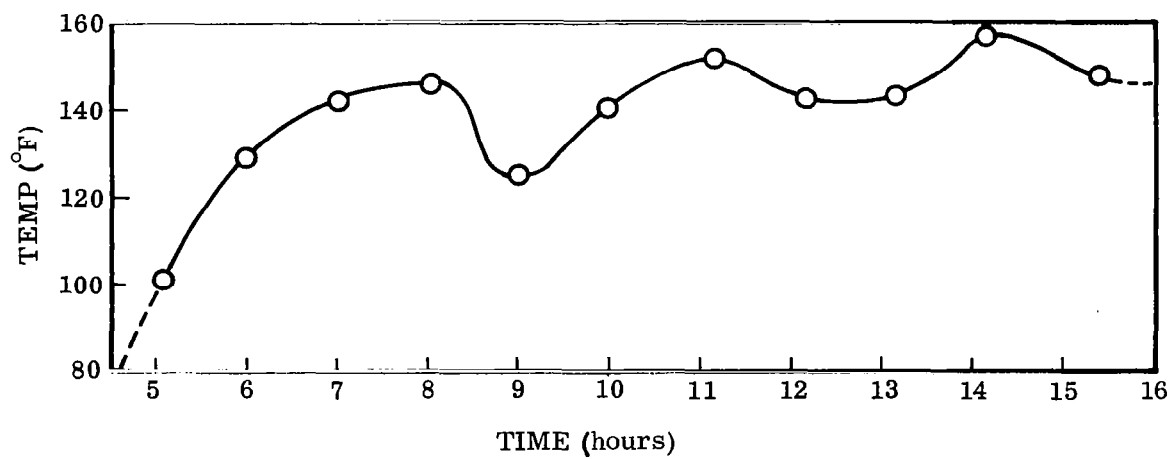
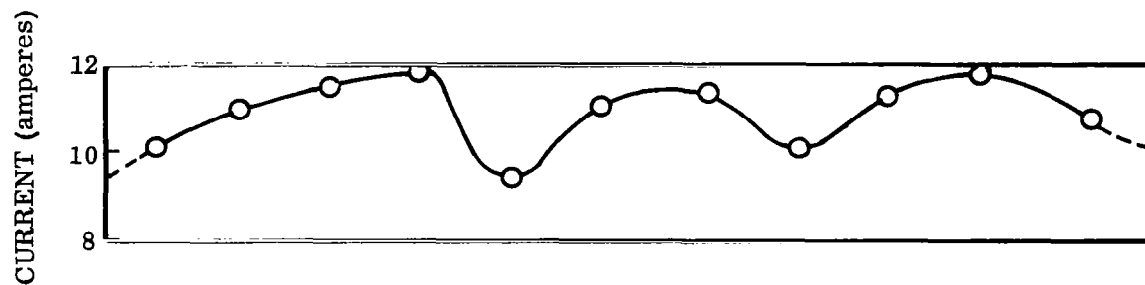
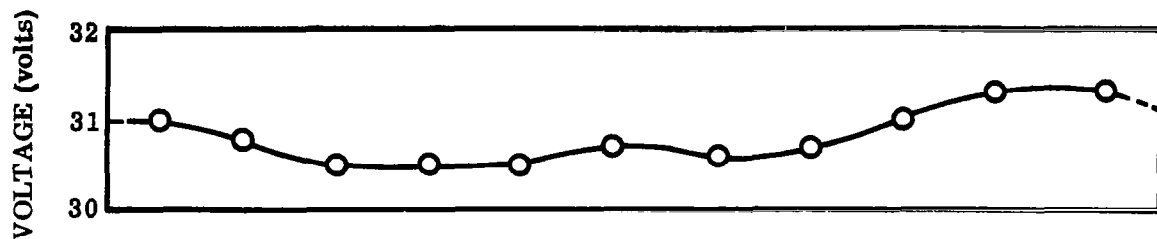


Figure 8.2-31. SAI Test Data, Electrolysis Module B



NOTE: MODULE OPERATED FOR 24.8 HR
PRIOR TO TEST

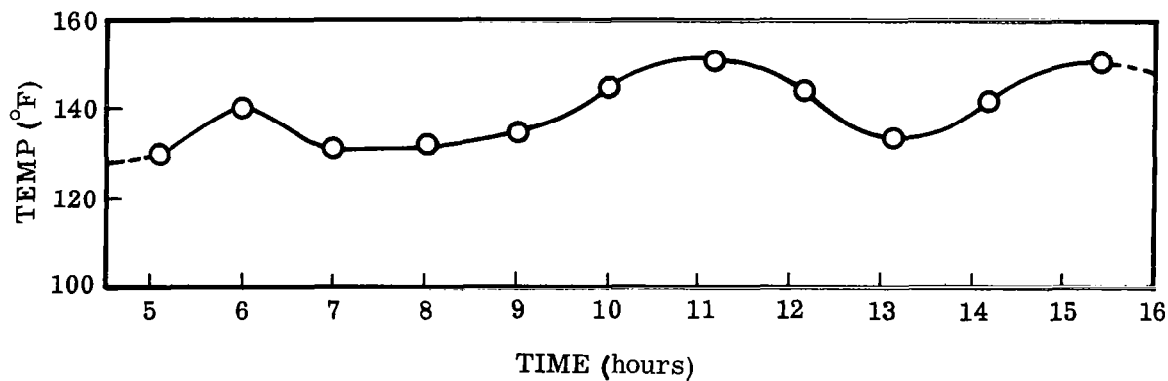
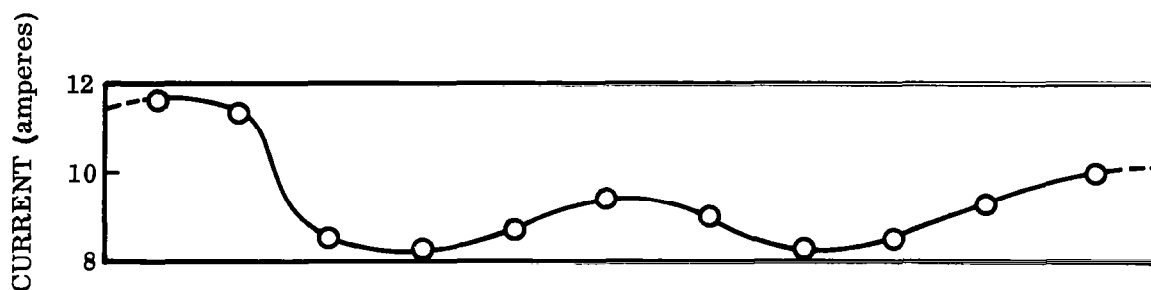


Figure 8.2-32. SAI Test Data, Electrolysis Module C

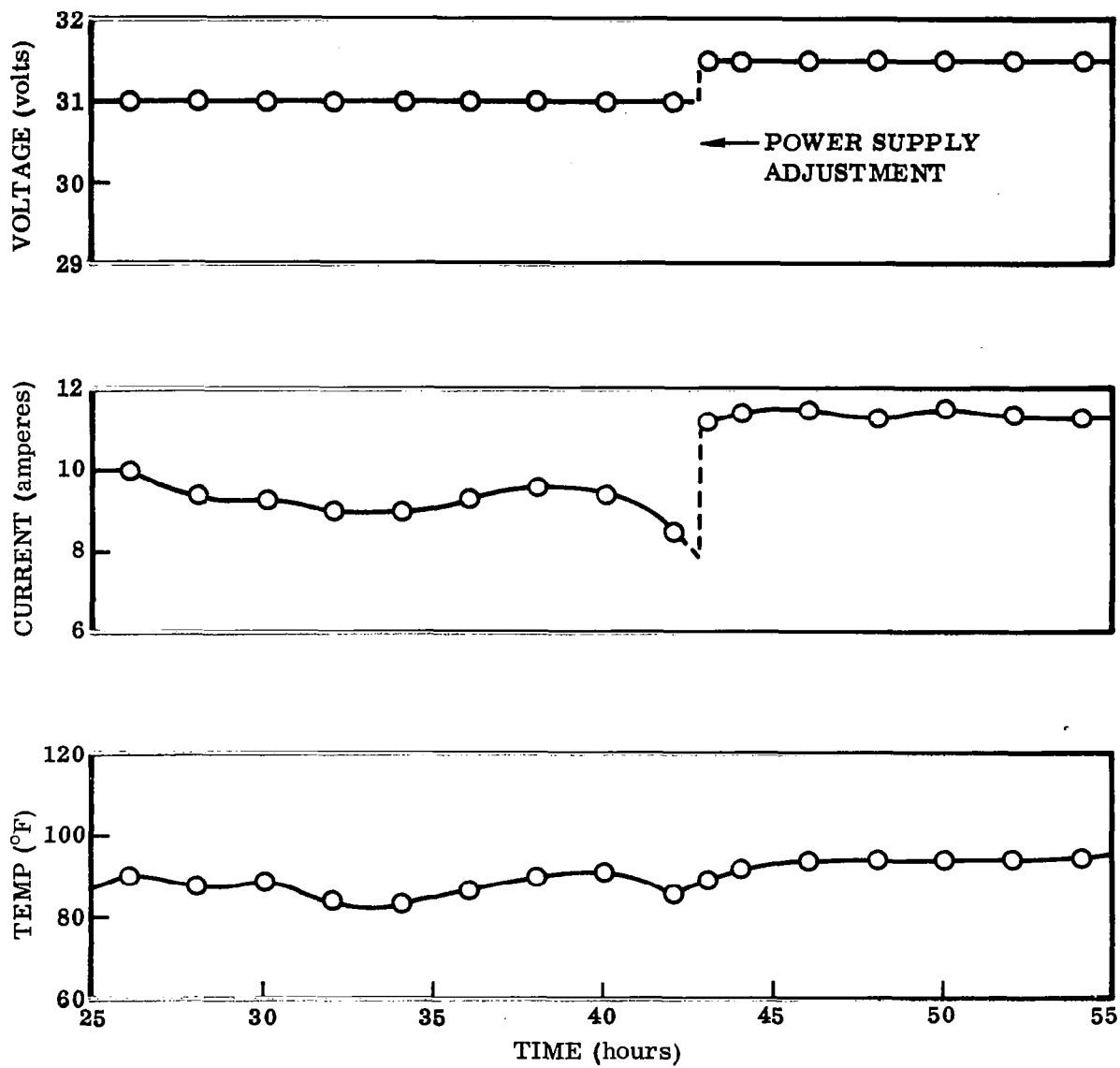


Figure 8.2-33. SAI Test Data, Rebuilt Module A

8.2.3.3 Convair Functional Checkout. The first tests performed at Convair on the electrolysis unit were functional checkouts of the unit using only Module B. The tests were performed according to the procedures given in General Dynamics/Convair Report "Electrolysis Unit Functional Checkout", dated 16 March 1965, and submitted to NASA. A summary of the results is given below.

The unit, without Module B, was found to be leak-tight, and it checked out electrically. The pressure regulators in the unit, however, exhibited large droop characteristics and did not seat positively. They were unsatisfactory for accurate pressure control and were later replaced. When Module B was leak checked, several leaks were found at lock-wired tygon-to-metal tubing connections. These connections, of which there were about 100 per module, were generally difficult to maintain tight, especially in the coolant circuit that operated at about 25-psig internal pressure.

With Module B installed, the unit was operated in the test bed for initial checkout. During the first run, the module current could not be raised to the specified 10.5 amperes, and a separate voltage supply had to be installed outside the test bed to supply the unit current. The stack voltage required to attain 10.5 amperes was about 32 volts, which was higher than the rating on the control components within the unit (such as the relays). Therefore, the control circuits and stack circuits were subsequently separated. The control components were powered by the test bed 28-volt supply, and the stack circuits were connected to a separate power supply of higher voltage.

During one test, acid was carried over into the gas output lines and deposited in traps at the rear of the unit. This type of acid carryover had been previously experienced and indicated the need for traps in the module gas lines upstream of the unit manifolds and test-bed lines. Such traps were later designed and installed to prevent further accidental contamination of the unit manifolds and valves.

Manual temperature control by means of the coolant flow required considerable attention. An active temperature controller was recommended and later installed.

The quantity of H_2 and purity of the H_2 and O_2 output gases were also measured during functional testing. The quantity of H_2 output agreed with the current drawn by the stack according to Faraday's Law. The H_2 purity was about 100 percent (exclusive of H_2O) and the O_2 purity was about 60 percent. The O_2 stream contained about 40-percent N_2 due to a leak that had developed inside the module.

Following the functional operation of the unit, Module B was removed from the test bed and inspected. The N_2 -to- O_2 leak was found to be at the base of the small O_2 output tubes emanating from the individual O_2 current-carrier assemblies. Repair of these leaks required stack disassembly and was scheduled to be done after completion of the initial evaluation tests and first NASA witnessed test of 8 April 1965.

8.2.3.4 Unit Evaluation. Further testing at Convair was limited by the design problems encountered and the time required to make modifications and repairs. Most of the testing was done to evaluate such modifications and the resulting operational characteristics of the unit. The work and testing performed is described below.

Initial Tests at 10 psia. Following the initial functional checkouts, the unit was run in the test bed at 10 psia. The unit and Module B performed satisfactorily at the lower pressure. Following this run the module was flooded with coolant from the separation of a 1/8-inch tygon-to-metal coolant-line joint. Following this, all 1/8-inch metal coolant lines were flared to prevent such separation from recurring.

The operation of the electrolysis unit was demonstrated to NASA along with the other test-bed units on 8 April 1965 with the test bed at 10 psia. The unit was not integrated with the Bosch reduction unit and only Module B was run. Typical test data are shown in Table 8.2-XXI.

Coolant-Circuit Pressure-Drop Tests. Unit and module pressure-drop tests were run in conjunction with improving stack-temperature control. The coolant-circuit pressure-drop characteristics with N_2 were checked to see if air from the cabin air cooling system could be used for stack cooling. The pressure drop with N_2 is shown in Figure 8.2-34 and was too high to use the cabin air circuit for cooling.

The pressure drop of Module B was checked with water. The results are shown in Figure 8.2-35. Theoretical corrections were applied to convert from the pressure drop with water to propylene glycol.

A test was also run on the test bed and the unit manifold pressure drop with propylene glycol. The pressure drop included the stainless-steel plumbing lines running to and from the main 5/8-inch test-bed coolant line. These lines were included to obtain an estimate of the pressure drop required from an orifice placed in the main line to provide coolant flow to the unit. No modules were available at the time of the test, so a 1/4-inch copper tube about 1 foot long was connected to the unit bulkhead fittings where Module B would normally have been connected. The other four bulkhead fittings were capped. The measured pressure drop was, therefore, approximately that of the unit, to which the pressure drop of the three parallel modules would have to be added. The data are presented in Figure 8.2-36.

A 0.199-inch-diameter orifice was placed in the main test bed coolant line to provide flow to the electrolysis unit. The pressure-drop characteristic of this orifice is shown in Figure 8.2-37.

Table 8.2-XXI. Electrolysis Unit Test Data*

TIME	TWO HOURS AFTER START
Module	B (ONLY)
Cell Voltage 1	1.84
Cell Voltage 2	1.81
Cell Voltage 3	1.86
Cell Voltage 4	1.83
Cell Voltage 5	1.85
Cell Voltage 6	1.84
Cell Voltage 7	1.85
Cell Voltage 8	1.87
Cell Voltage 9	1.86
Cell Voltage 10	1.85
Cell Voltage 11	1.85
Cell Voltage 12	1.88
Cell Voltage 13	1.85
Cell Voltage 14	1.86
Cell Voltage 15	1.84
Cell Voltage 16	2.07
Module Current (amp)	8.9
Module T (° F)	91
Coolant T in (° F)	40
Coolant T out (° F)	42
N ₂ Pressure (psig)	8.9
H ₂ O Pressure (psig)	6.5
H ₂ Pressure (psig)	7.5
O ₂ Pressure (psig)	9.6
Line Voltage	31.1
Total Current (amp)	9.6
H ₂ Flow (SCFH)	2.4

*8 April 1965

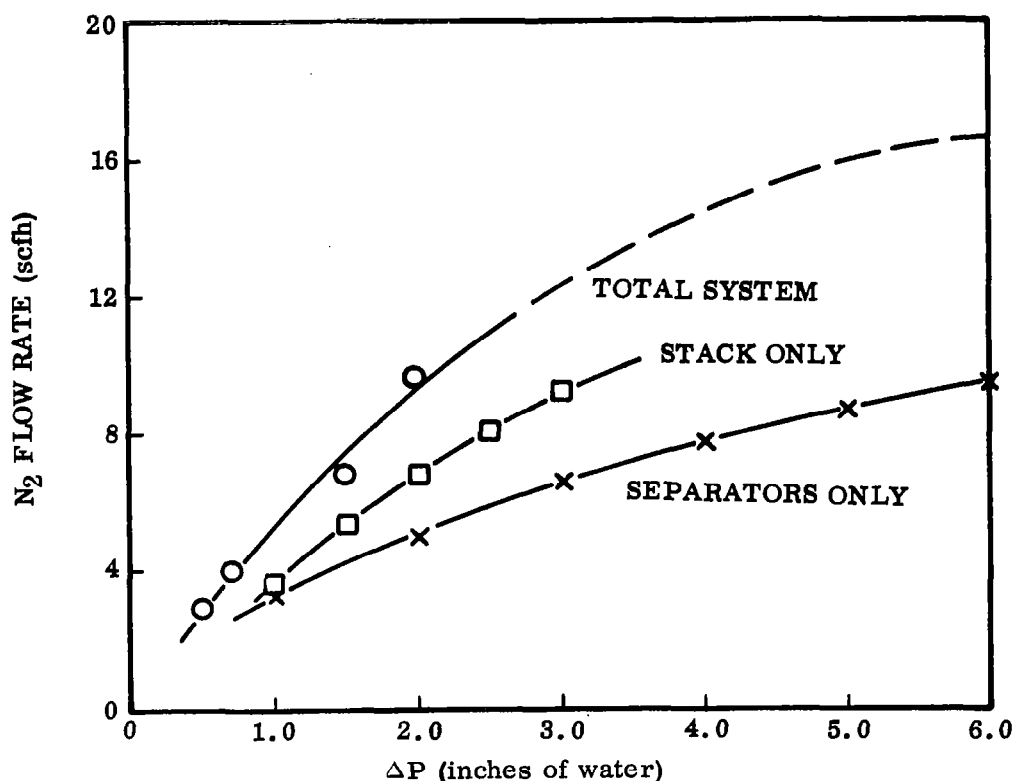


Figure 8.2-34. N_2 Flow vs. Pressure Drop, Electrolysis Module B Coolant Test.

Module A and C Checkout. Modules A and C were rebuilt by GE, tested, and accepted by Convair. Module C was installed in the test bed for checkout on 25 May 1965 and operated satisfactorily. Modules A and C were checked out successfully together on 27 May 1965.

Module B Cell-Replacement Tests. Module B was completely disassembled and the leaks in the current carrier assemblies were repaired. Following this repair, Module B was found to have some very high cell voltages. Considerable bench testing was performed from 27 May to 8 June to find the cause of the high voltages. Most of the tests were run at very low current to avoid overheating and damaging cells.

The high voltages were originally thought to be due to contact resistance between the titanium current carriers stacked back-to-back within the stack. The contact resistance was checked out in several ways but was found to be very small and could not account for the high cell voltages. Stack-electrolyte level and specific gravity were also checked and found satisfactory. Fresh electrolyte was flushed through the stack. Nothing was found that could explain the high cell voltages, and they could

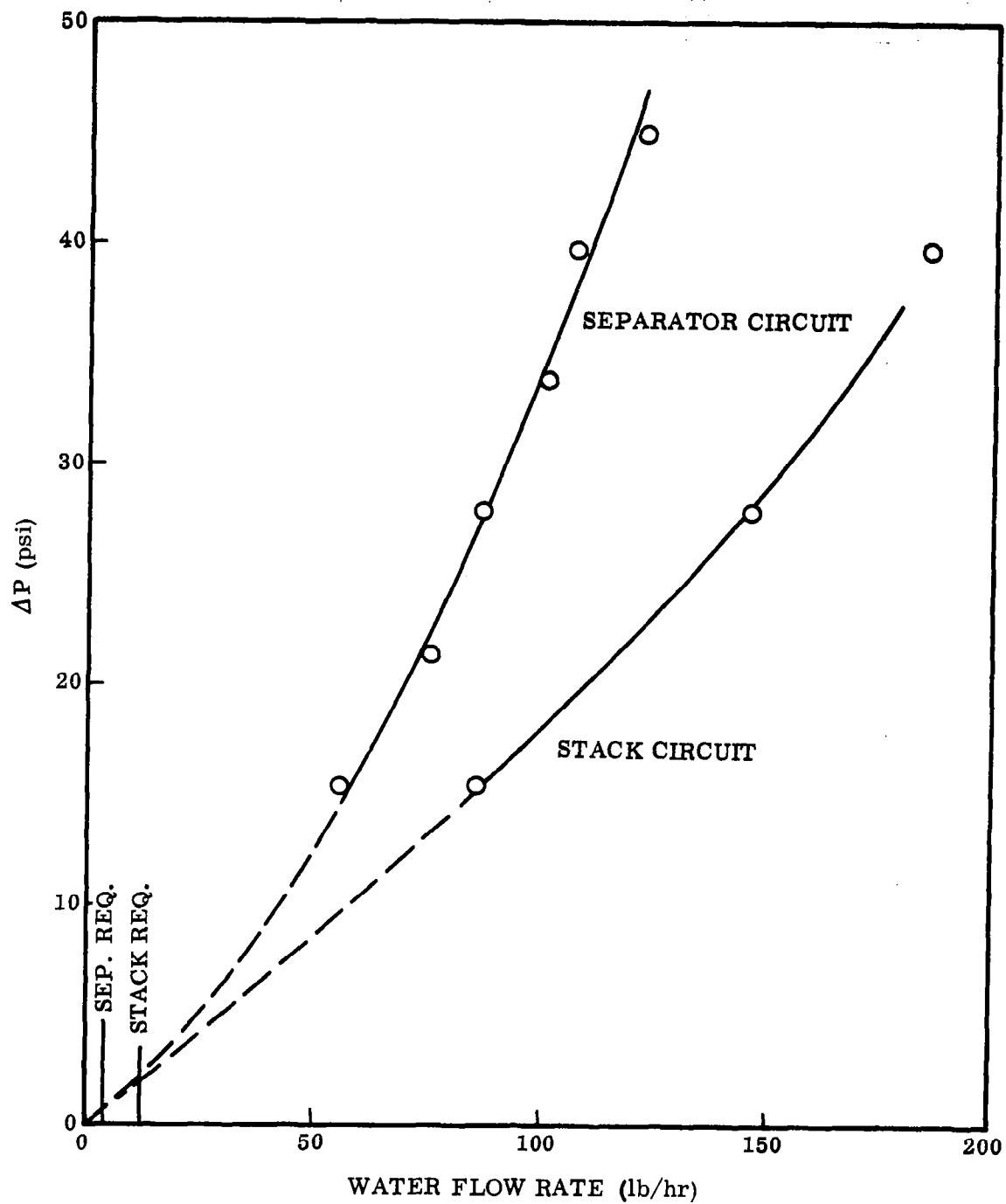


Figure 8.2-35. Pressure Drop vs. Water Flow,
Electrolysis Module B Coolant Test

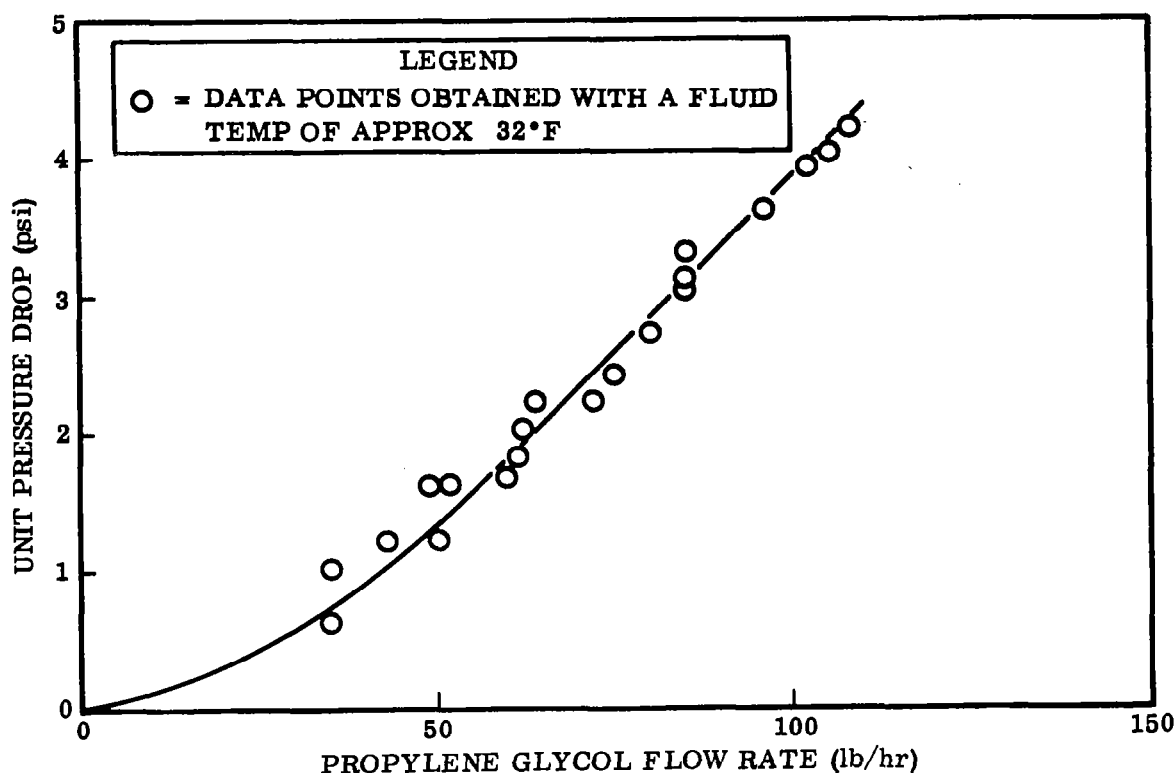


Figure 8.2-36. Electrolysis Module B Glycol Flow
Versus Pressure Drop

only be attributed to the degradation of the membrane assemblies. Eighteen new assemblies were obtained from GE and were substituted into the stack in place of those in the cells with the highest voltage drops. The cell positions were changed so that the new and old cells were alternately stacked. Following re-assembly, the stack was again run on the bench. All the new cells registered low voltages of around 1.75 volts. The old cell voltages were higher but were about the same as they had been before the repair. The stack and module were therefore re-assembled and installed in the test bed.

Temperature-Controller Tests. After installation of the new temperature controllers and the revised coolant circuit using higher temperature fluid, several tests were run to determine the stack temperature behavior. Module A was first run on 10 June 1965, and the temperature fluctuations were recorded. (See Figure 8.2-38.) The controller held the temperature within a range of about 3°F, and the new coolant circuit using the orifice provided adequate cooling capacity for the single module. Next, the three modules were run concurrently with all the manual coolant-line valves wide open. (See Figure 8.2-39.) The controllers and cooling circuit provided satisfactory temperature control for all three modules. The valves can be closed down to increase the cycle period and reduce the exercise rate of the solenoids. However,

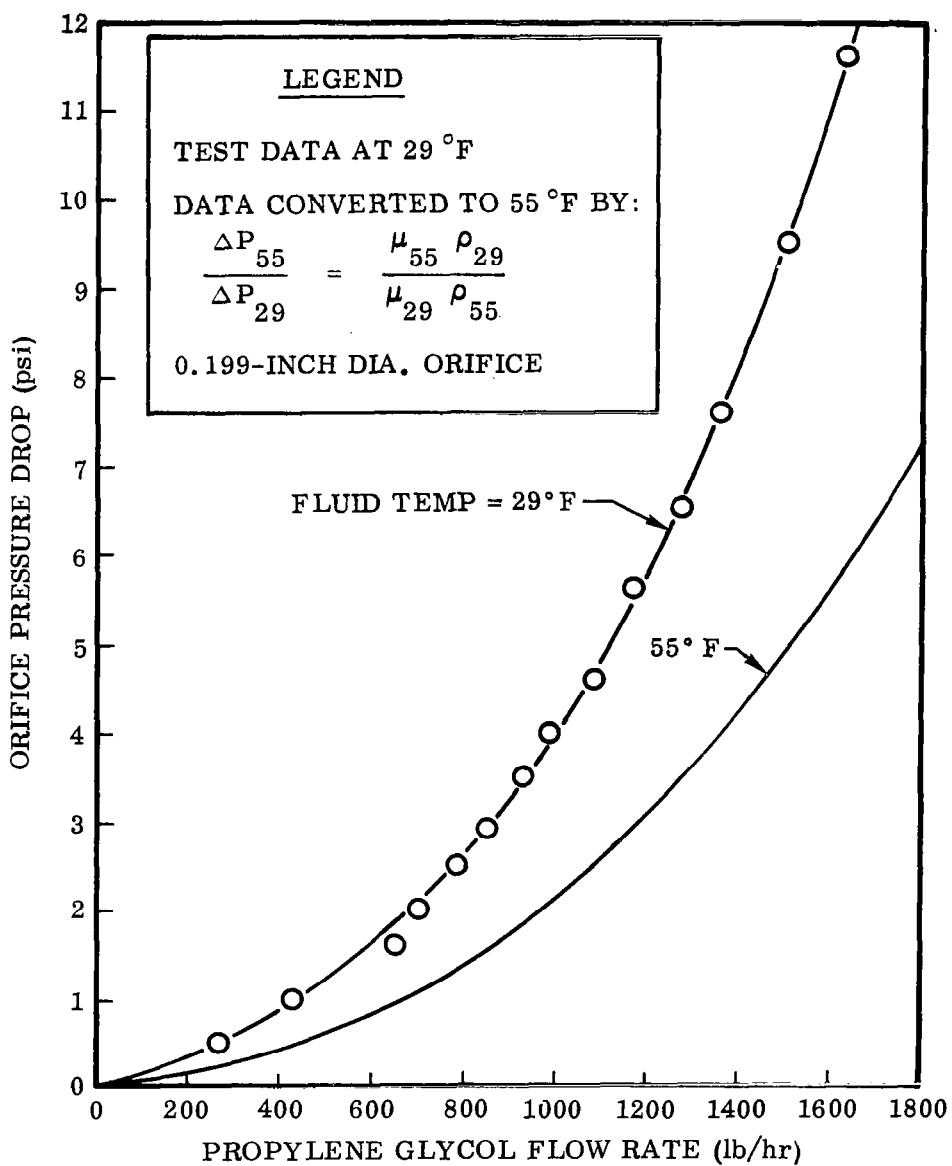


Figure 8.2-37. Electrolysis Unit Coolant Flow Calibration

8-115

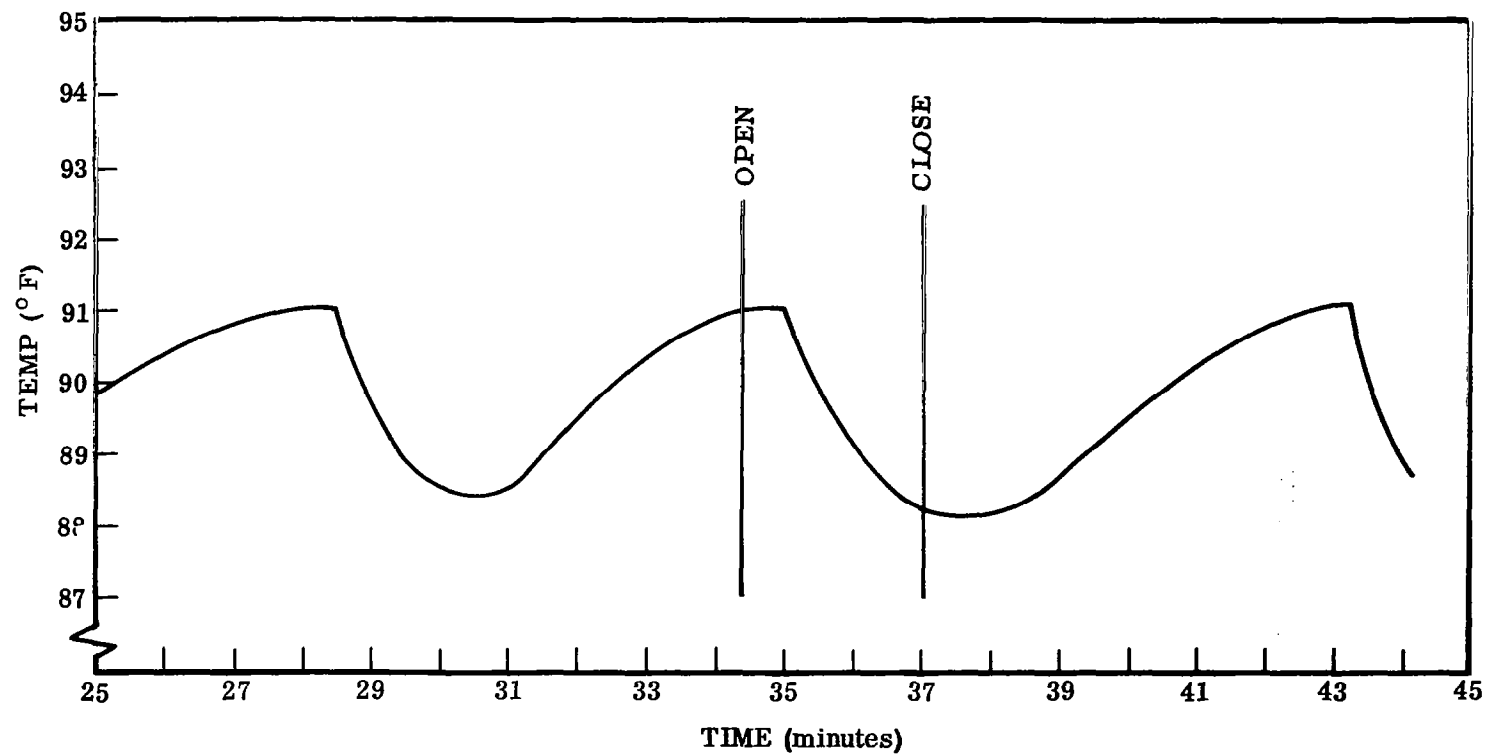


Figure 8.2-38. Temperature Controller Test, Module A

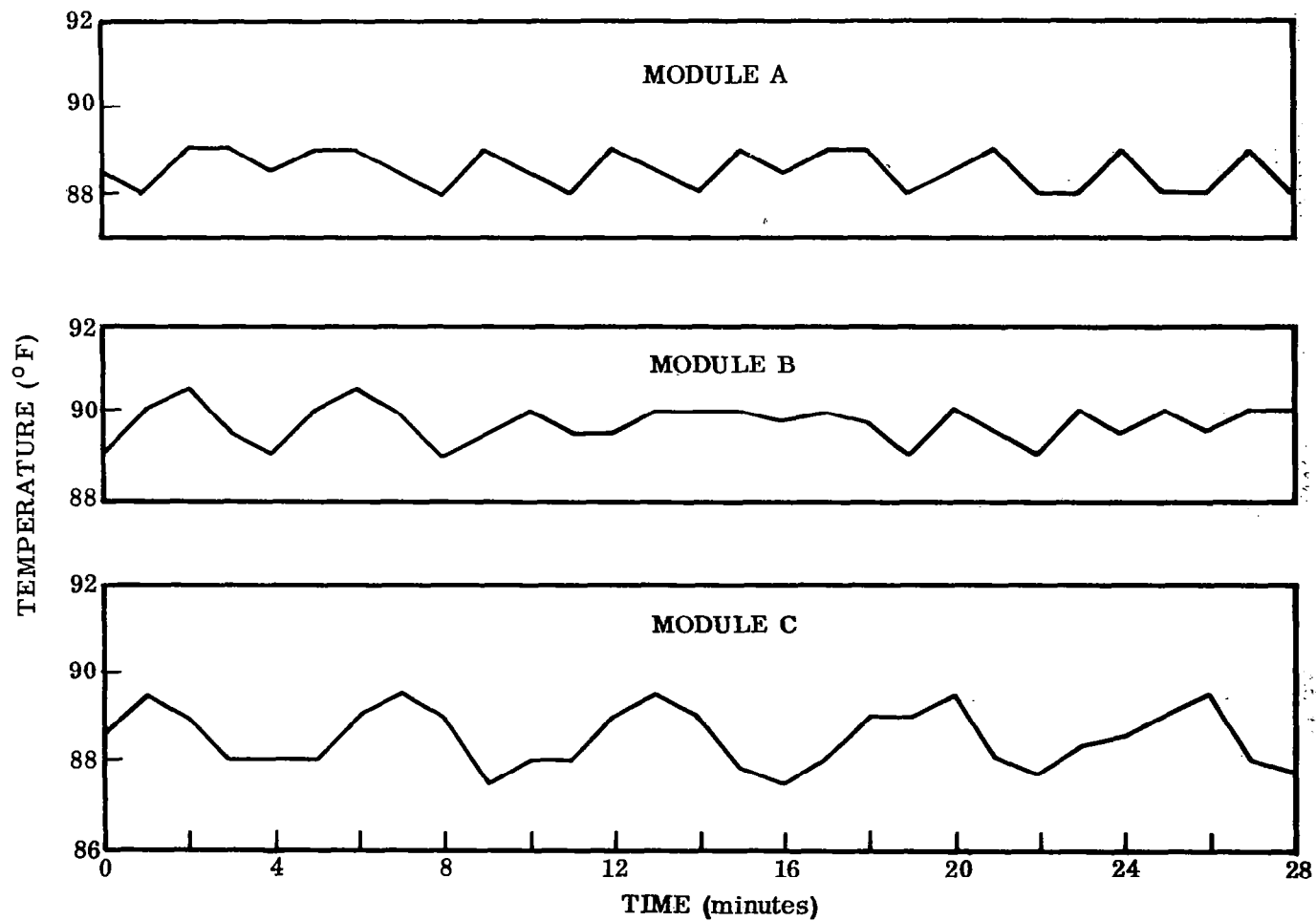


Figure 8.2-39. Temperature Control Test, Three Modules, All Valves Open

care must be taken not to close the valves too much such that full flow will not sufficiently cool the modules. The module coolant requirements increase during operation. During the first several hours of operation the modules become polarized and the unit voltages rise. Hence, heat generation increases within the stacks and increasing coolant flow is required.

Pressure-Regulator Characteristics. The pressure regulators provided with the unit had excessive droop characteristics. Therefore, new regulators were ordered for the water feed, H₂ vent, and the O₂ output. Before installation the pressure-flow characteristics of these regulators were checked with N₂ and H₂O. Figures 8.2-40 and 8.2-41 show the total change over the design flow range to be in the order of 0.1 psig. This value is considerably better than the original regulators, which exhibited a change of about 2 psig over the design flow range.

Final Integrated Testing. All three modules were checked out on the unit, and the unit was then used to feed H₂ to the reduction unit. With almost zero flow through the H₂ vent regulator, the unit H₂ pressure dropped only about 0.3 psig from the full H₂ vent flow condition. The O₂ pressure was set and held at about 7.5 psig. All unit pressures held steady, and the temperature held at 89 ± 2° F. The gas output as measured on the flowmeters agreed with the unit current, and the gases were better than 99.9 percent pure. Data from the final NASA demonstration test are shown in Table 8.2-XXII, and are typical of the final test data obtained on the unit.

8.2.3.5 Unit Characteristics. The pertinent design and testing experience accumulated by Convair on the electrolysis unit is discussed below.

Basic Cell Characteristics. The worst potential problem with the basic cell appears to be a current-carrier-assembly degradation, which results in excessive cell voltages. Several cells became degraded at GE during the course of unit acceptance testing. When the cells were removed from the stack and opened, the oxygen-side membranes had noticeably clear puffy appearances. The membranes were separated from the titanium current carrier, and the platinum electrode bulged in the direction of the electrolyte pockets. The H₂-side membranes were coated with platinum black and showed some membrane separation but in smaller areas.

Membranes also exhibited excessive voltages after current-carrier-assembly repair at Convair. About 9 cells exhibited high voltages, and various tests indicated that the high voltages were due to current carrier assembly degradation. Upon inspection, however, the membranes appeared the same as normal membranes (no puffy or separated areas). Only one difference was noted on several membranes that showed very small areas of the order of 2 mm² where the platinum black had evidently been depleted. This was observed in several spots along the membrane where the spacer ribs had left the membrane uncoated with platinum and, therefore, transparent. At these spots, the titanium current carrier could be seen through the membrane instead

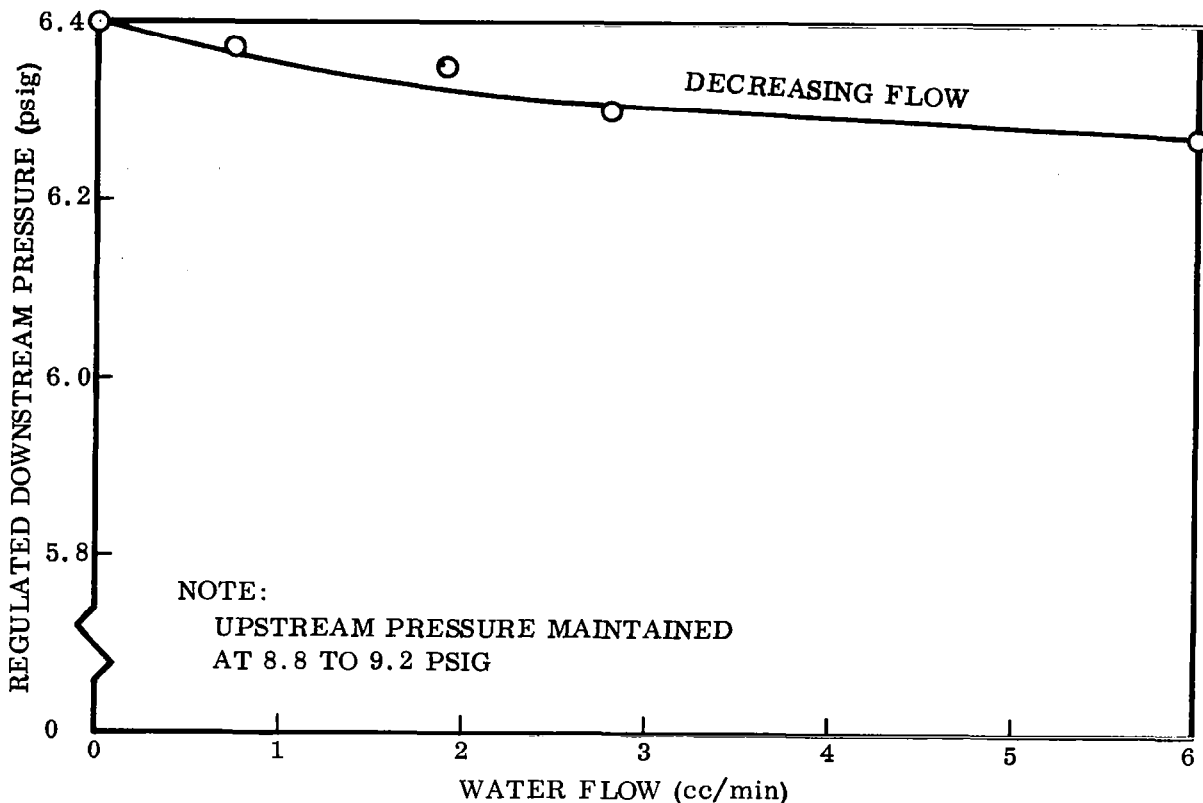


Figure 8.2-40. Characteristics of Coolant-Pressure Regulator

of the black electrode material. This suggests that the high voltage could have resulted from platinum loss and a resulting increased electrical resistance. Hence, the cell-degradation problem may be related to the platinum black-electrode characteristics.

The platinum black electrodes are used in the cells to minimize the electrode overvoltage and possibly because their porous nature is adaptable to mating with the flexible membranes. A disadvantage of the porosity, however, is that the electrode will deteriorate faster than solid metal electrodes. This has evidently happened in the unit since fine black particles have been noted in the electrolyte, and a black or sometimes silvery coating has been observed on the electrolyte side of the membranes. The coating is in the vicinity of the metal coolant tubes and sometimes exhibited the pattern of the tubes. The electrode particles may become dislodged and migrate through the membrane and into the electrolyte, due to electrophoresis, or the platinum black may react to form some compound that migrates electrolytically and is then plated out. Whether this migration definitely caused any of the degradation problems so far experienced with the unit is unknown. Electrode deterioration does occur through some mechanism, however, and would probably eventually cause the cell voltage/current characteristic to degrade.

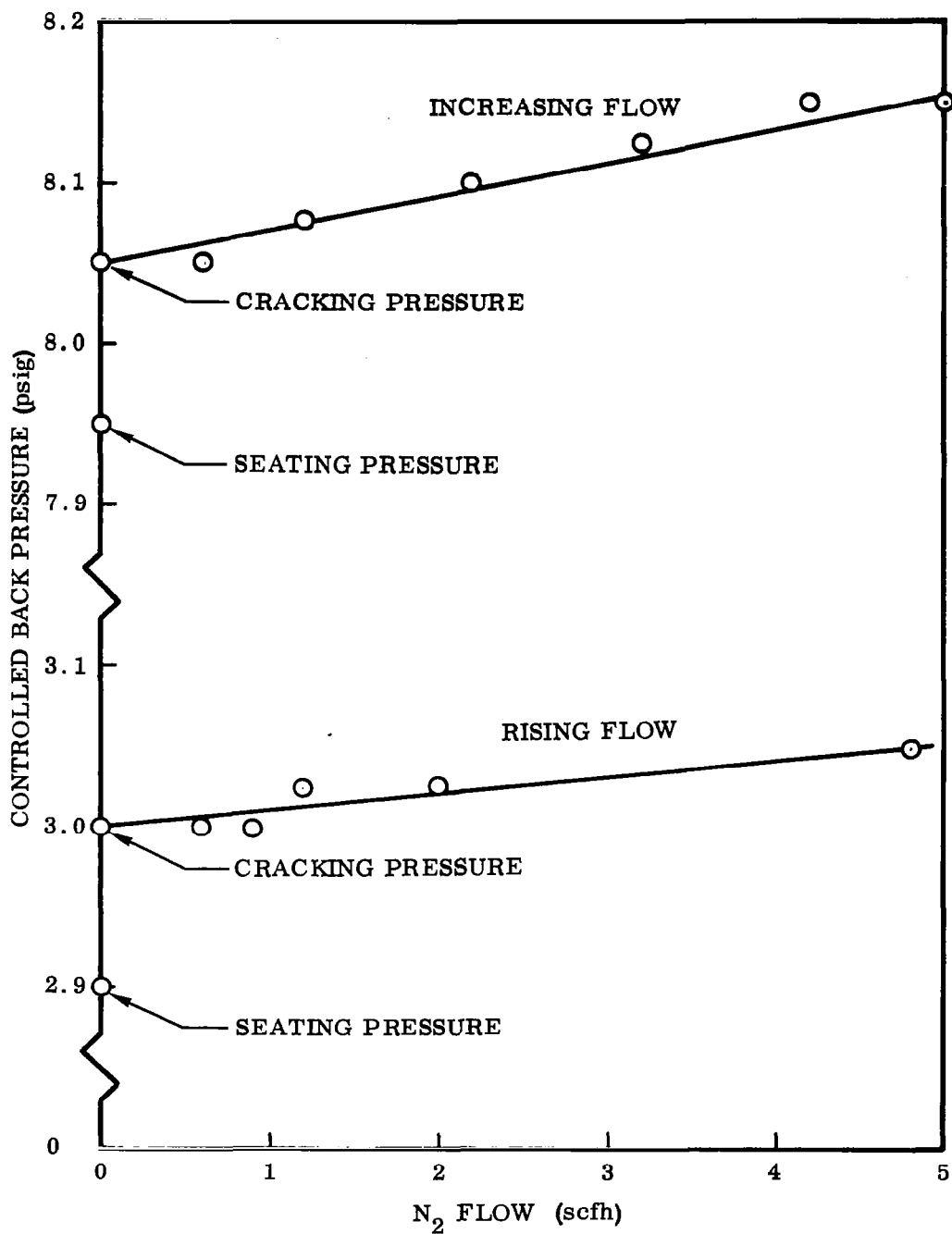


Figure 8.2-41. Characteristics of Gas Pressure Regulators at Two Set Points

Table 8.2-XXII. Typical Final Data* on Electrolysis Unit

Module	TIME					
	15 MINUTES AFTER START			TWO HOURS AFTER START		
	A	B	C	A	B	C
Cell Voltage 1	1.88	1.82	1.90	1.89	1.88	1.94
Cell Voltage 2	1.78	1.92	1.81	1.85	1.98	1.87
Cell Voltage 3	1.77	1.81	1.83	1.85	1.88	1.88
Cell Voltage 4	1.81	1.93	1.81	1.88	2.00	1.88
Cell Voltage 5	1.81	1.76	1.79	1.88	1.83	1.85
Cell Voltage 6	1.81	1.87	1.81	1.89	1.95	1.88
Cell Voltage 7	1.81	1.78	1.81	1.89	1.87	1.89
Cell Voltage 8	1.78	1.89	1.79	1.76	1.97	1.86
Cell Voltage 9	1.83	1.79	1.79	1.91	1.87	1.86
Cell Voltage 10	1.82	1.90	1.77	1.90	1.98	1.85
Cell Voltage 11	1.82	1.76	1.81	1.90	1.85	1.88
Cell Voltage 12	1.82	1.88	1.79	1.90	1.96	1.86
Cell Voltage 13	1.78	1.75	1.80	1.86	1.83	1.88
Cell Voltage 14	1.82	1.76	1.79	1.90	1.84	1.86
Cell Voltage 15	1.83	1.76	1.81	1.90	1.82	1.88
Cell Voltage 16	1.84	1.86	1.84	1.91	1.94	1.91
Module Current (amp)	11.1	8.5	9.8	11.4	8.6	10.4
Module T (° F)	89	89	87	89	89	89
Coolant T in (° F)	71			75		
Coolant T out (° F)	76			80		
N ₂ Pressure (psig)	8.9			8.9		
H ₂ O Pressure (psig)	6.3			6.3		
H ₂ Pressure (psig)	7.2			7.2		
O ₂ Pressure (psig)	7.4			7.4		
Line Voltage	31.5			32.8		
Total Current (amp)	29.5			30.8		
Coolant Flow (lb/hr)	9.4			8.5		
Cabin Pressure (psia)	10			10		

*13 July 1965

A weak point in the mechanical design of the current-carrier assemblies is the bonding around the edge of the fiberglass frame. The metal-to-fiberglass bond will break if the assembly is not handled carefully. The gas tubes are particularly vulnerable to loosening since they stick out and can be easily bumped or forced so that the base is overstressed. The tubes are particularly subject to overstress, and care must be exercised during the process of lock wiring the tygon tubes to the metal O₂ and H₂ outlet tubes.

Between the two membranes the molded rubber spacer is used to form the electrolyte chamber. When the stack is assembled and bolted together, the spacers are compressed to form the edge seal.

The spacer rubber was quite soft and had to be compressed more than expected to provide a good seal. This resulted in a narrower electrolyte pocket than expected and some concern was raised over possible shorting through the coolant tubes. No detrimental performance effect was noted, although the current flow was affected by the tubes since the image of the tube could be seen in the platinum deposits on the membranes. The effect of the coolant tubes on current flow and distribution would exist independent of electrolyte-chamber width but would be more pronounced with a narrower chamber. The magnitude of the effect on performance cannot be estimated.

The cell-coolant tubes and the electrolyte tubes passed through holes in the edge of the spacer. Originally there was no seal except the elastic pressure of the rubber around the tubes. To enhance this seal, an epoxy fillet was applied around the outside junction of the tube and rubber spacer. Although this was generally satisfactory from a leakage standpoint, disassembly of the cells was more difficult, since the epoxy fillet usually had to be removed. The coolant tubes are spaced within the electrolyte chamber at 1.3-inch intervals, but the heat is generated over the full area of the cell. The resulting temperature gradients will tend to reduce cell efficiency since the membrane is temperature limited and yet cell efficiency improves with high temperature. The extent of the gradient has not been analyzed, but will be aggravated by zero gravity. In addition to the localized temperature gradient due to the tube configuration, an additional gradient exists in the direction of flow through the tubing. This latter gradient can be reduced by using a high temperature coolant.

Module and Stack Characteristics. As noted previously, the tygon tubing used within the modules was difficult to seal to the metal tubing. The tygon, however, has the advantage of being flexible, electrically nonconductive, transparent, light weight, and noncorrosive. It also has the disadvantages of expanding and rupturing at low pressures, being difficult to make into positive joints, and it discolors with time. The most trouble encountered with the tygon tubing was in the high-pressure coolant circuit. A different tubing material would be a definite advantage for this circuit. Caution should be exercised, however, not to introduce shorts between the cells.

An exact volume of the gas and electrolyte chambers within the stack is not meaningful since these volumes are changeable. They will change depending on the compression of stack by the bolts and also depending upon the pressure differentials across the membranes and the resulting membrane deflection. However, approximate values for the H₂ volume and the electrolyte volume were measured during testing at Convair. These may be of value in calculating approximate leakage rates, stack electrolyte level, etc., and are given below.

Approximate Module H₂ Circuit Volume = 2500 cc

Approximate Stack Electrolyte Volume = 1800 cc
(Gas circuits unpressurized)

The H₂ volume includes the separator and tubing. It was computed by measuring 140 ml of water displaced by N₂ from the stack while the stack N₂ pressure dropped from 22 inches to 0 inch of water gage. (An isothermal expansion was assumed, and membrane deflection was ignored.) The electrolyte-chamber volume was obtained merely by measuring the amount of distilled water drained from a full unpressurized stack. Stack B was used for these measurements, and the stack was compressed so that the distance between the inside of the fiberglass end-plates was about 5.9 inches.

Sulfuric acid is used in the stack because it is compatible with the membranes. It is a good low-resistance electrolyte but has the disadvantage of being very corrosive. It will attack almost all stainless steels. Carpenter 20 type stainless steel was used in the module where the lines contained acid. However, leakage and corrosion were experienced quite frequently during the program.

The acid concentration used is 25 percent. It can be checked by the specific gravity as shown in Figure 8.2-42.

The modules utilize propylene glycol coolant for two purposes. One purpose is to cool the output O₂ and H₂ and condense any vapor in these gases. The other purpose is to cool the stacks. The coolant temperature for maximum condensation should be as low as possible without freezing the condenser, or about 35°F. On the other hand, the coolant temperature to the stack should be close to 90°F for best electrolysis efficiency. Since only one main coolant line is plumbed to the electrolysis unit, a compromise on temperature is necessary. Hence, a coolant temperature of about 68°F was used in the test bed. This prevented condensation in test-bed lines yet cooled the stacks with a minimum temperature gradient from cell coolant inlet to outlet. Also, the higher coolant temperature minimized the transients due to the on-off flow control.

Unit Characteristics. The unit requires accurate pressure control to prevent leakage across the membranes or the porous separator plates. The prime consideration is the pressure differential between the H₂ and O₂ gas circuits and the electrolyte circuit. A slight overpressure of the gas circuit is required to force condensate through the porous plate separator and also to inhibit electrolyte seepage through the membranes. On the

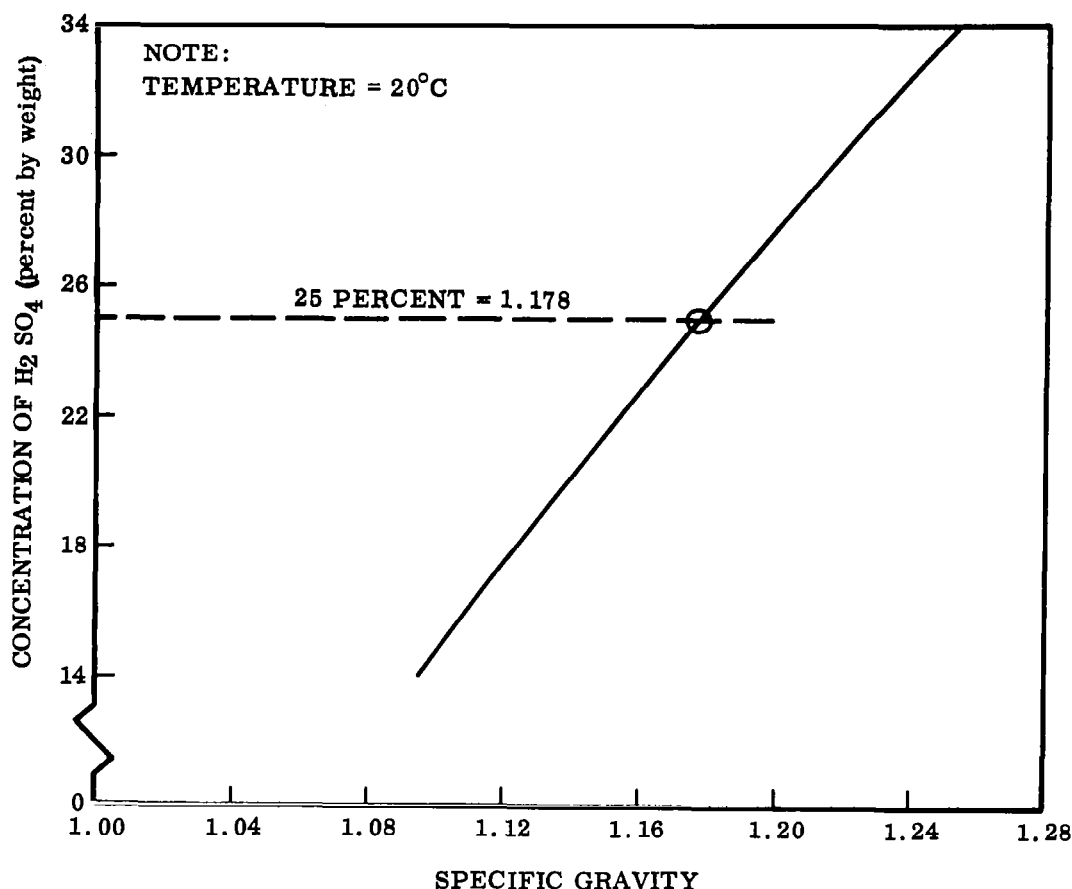


Figure 8.2-42. Specific Gravity of Sulfuric Acid Solutions

other hand, the higher the gas side overpressure, the greater the possibility that gas will be forced through the porous plates into the electrolyte chambers. Convair successfully ran the unit with a nominal gas overpressure of 1 psi as read on the pressure gages.

In the existing pressure-control system, the H₂O, H₂, O₂, and N₂ pressures are independently set and are referenced to cabin pressure. This design was used to isolate the H₂ from the O₂ and also to allow the use of simple standard pressure regulators. The overall regulation system, however, is quite complex. It might be improved if the pressures were cross-referenced since the primary concern is the control of differential pressures. Also, a lower absolute pressure in the unit might require fewer safety backup pressure controls to protect the membranes. An improved pressure-control system should be developed for the unit. It might include special regulation components.

The unit requires the use of a pressurization yoke during standby and during startup. The yoke is unwieldy, and the continuous pressurization requirement during standby is undesirable. Pressurization is used during standby to keep electrolyte from passing through the separators and membranes into the gas circuits. This requirement is questionable since the stack sat on the bench for several days at a time at Convair without any observable electrolyte passage. Further tests on the modules should be run to verify the need for standby pressurization.

The unit is pressurized with the yoke during startup to minimize transient pressure differentials. The allowable differentials have never been checked on the modules because of the possibility of damaging the stacks. If the allowable pressures were checked and found to be appreciable, the yoke might not be required during startup. Also, if the absolute pressures of the unit could be lowered it would help eliminate the need for startup pressurization.

The yoke, as well as the other fluid lines, is connected to the rear of the unit by means of quick-disconnects. Several of these disconnects became jammed and had to be replaced during testing at GE and Convair probably from contact with sulfuric acid.

8.2.4 CONTAMINANT CONTROL. During the test period it was not apparent that filter loading occurred in any of the filters, but no quantitative information was obtained regarding filter performance. Tests of the catalytic burner were only slightly more quantitative in that burner characteristics were examined with respect to operational parameters, but only vendor SAI tests yielded significant quantitative information regarding oxidation characteristics. The following discussion of tests results deals only with the catalytic burner subsystem.

8.2.4.1 SAI Tests. To demonstrate and evaluate the performance of the catalytic burners, and to show compliance with Convair Specification 64-02023, Revisions A and B, the vendor was required to subject the burners to a series of tests and measurements. Some deviations to the specification requirements were agreed to by Convair, NASA/LRC, and MRD. A complete description of these tests is contained in GATC Final Report MRD 1254-7080, dated April 1965. Major results of those tests are included in this report. Both units were subjected to essentially the same tests although one unit (S/N 001) was tested using the palladium catalyst and the other (S/N 002) was tested using the GAT-A-LYST catalyst. The copper-oxide/manganese-oxide catalyst was not tested.

Pressure and Leakage Tests. The units were subjected to a pressure of 33 inches of water gage. The total leakage was 0.0074 lb/hr for S/N 001 and 0.0019 lb/hr for S/N 002 compared with a maximum allowable leakage of 0.0099 lb/hr. With a 15-inch water differential (inlet side only pressurized through the heat exchanger to the catalyst container-wall seal) the total gross leakage (to both the system exterior and to the outlet side of the heat exchanger) was 0.0127 and 0.0130 lb/hr for S/N 001 and

S/N 002 respectively compared with a maximum allowable leakage of 0.0150 lb/hr. Leak tests were performed before and after the units were operated at full-flow capacity and normal operating temperatures of 700°F to 800°F.

System Pressure Drop. With tests running at atmospheric pressure ($\mu = 14.7$ psia), ambient air temperature of 75°F, and a catalyst-bed temperature of 700°F to 800°F, the pressure drop across either S/N 001 or S/N 002 was:

<u>Flow (lb/hr)</u>	<u>ΔP (inches of water)</u>
2	0.5
5	2.0
10	4.5
16	10.0

Heat Exchanger Effectiveness and System Power. Gas inlet and outlet temperatures averaged 80°F and 135°F respectively at a flow of 8.5 to 9.0 lb/hr. The catalyst-bed outlet temperature averaged 750°F to 800°F and the inlet temperature to the heater (at the exit part of the inlet side of the heat exchanger) was 700°F to 750°F. Using average temperatures:

Heat exchanger inlet (pass in)	=	80°F
Heat exchanger outlet (pass in)	=	725°F
ΔT	=	645°F
Heat exchanger inlet (pass out)	=	775°F
Heat exchanger outlet (pass out)	=	135°F
ΔT	=	640°F
Heat exchanger effectiveness	=	640/645 = 0.993

To maintain the catalyst bed at 750°F at 4.95 lb/hr (nominal design flow), the electrical power input was 83 watts on a continuous basis with a 90-volt input to the normal heater element, which has a resistance of 98 ohms.

Contaminant Oxidation Efficiencies. Tests were run at internal and external pressures of essentially 14.7 psia. To compensate for not operating at 10.0 psia, the gas-mass flow was increased to twice the flow requirement for all performance tests.

With a gas flow of 10 lb/hr and catalyst-bed temperature of 700°F-800°F, the burners removed contaminants as shown below.

<u>Contaminant</u>	<u>Concentration</u>		<u>Removal Efficiency</u>
	<u>Inlet</u>	<u>Outlet</u>	
CO	1200 ppm	3-5 ppm	99.75-99.58%
	10 ppm	--	Not tested
CH ₄	1%	0.01-0.015%	99.0-98.5%
	230 ppm	14 ppm	94.1%

For conditions of 14.7 psia, 700°F-800°F but at gas flows of 2 and 16 lb/hr the oxidation efficiencies were:

<u>Contaminant</u>	<u>Concentration</u>		<u>Removal Efficiency</u>
	<u>Inlet</u>	<u>Outlet</u>	
CO (2 lb/hr)	1200 ppm	2-5 ppm	99.84-99.58%
CH ₄ (16 lb/hr)	3300 ppm	200 ppm	94%
	230 ppm	25 ppm	89%

The inlet concentration of methane at 16 lb/hr was held at 0.33 percent to prevent the catalyst-bed outlet temperature from exceeding 1000°F.

8.2.4.2 Convair Functional Checkout. The catalytic burners were functionally evaluated in accordance with a prepared procedure. Significant results from this checkout were:

- Pressure sensing lines to gauges and switches required changing from 1/8-inch to 1/4-inch to achieve reasonable response times.
- All thermostat switches required resetting. This was done using the panel-mounted pyrometer.
- The high-temperature thermostat on Unit No. 2 was defective and will require replacing.

Time temperature history during heating of the units was obtained using only one heater initially and then utilizing both heaters. Pull-up time using only one heater was approximately 14 hours. When both heaters are used, pull up can be obtained in about 6 hours. This is shown in Figures 8.2-43 and 8.2-44. Figure 8.2-44 shows the effect of utilizing both heaters.

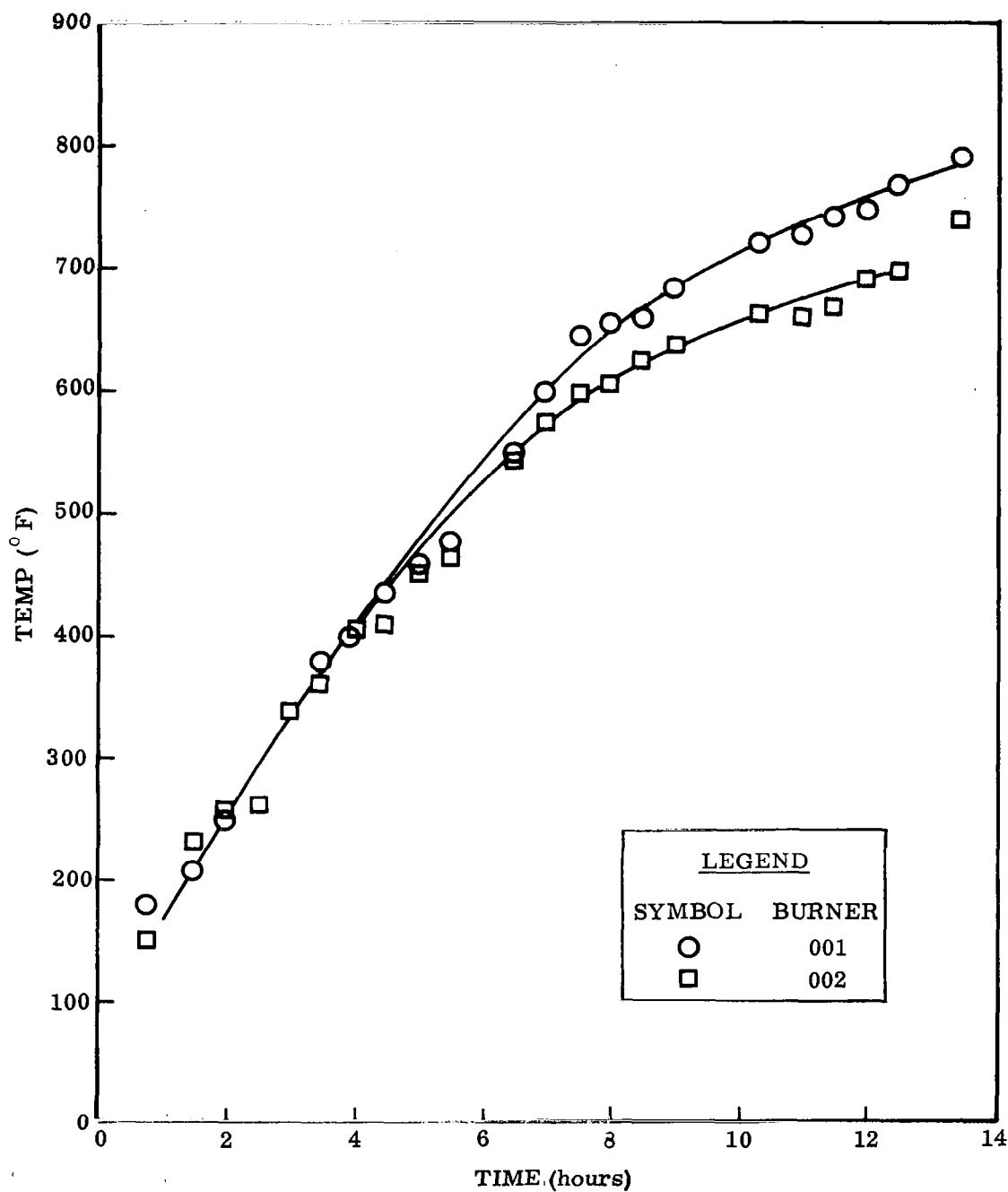


Figure 8.2-43. Catalytic Burner Heating Characteristic, Heater Mode Normal

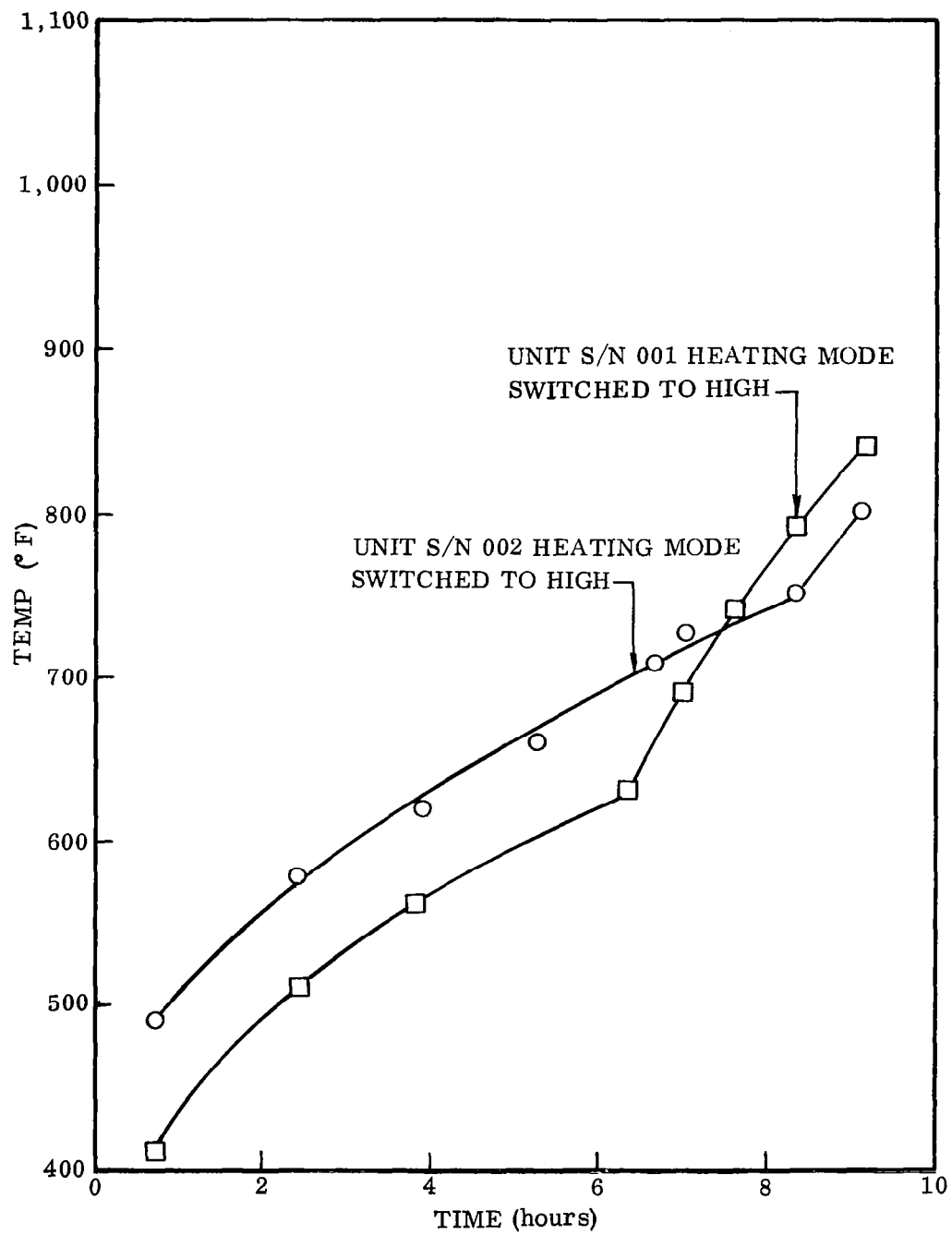


Figure 8.2-44. Catalytic Burner Heating Characteristic, High Position

Air flow through the units in normal mode (utilizing only the main cabin fan circuit for air flow) was as follows for sea level operation.

a. Parallel operation.

1. Both units together

(a) Unit No. 1 - $W_a = 5.8$ lb/hr

(b) Unit No. 2 - $W_a = 6.7$ lb/hr

2. Unit No. 1 only - $W_a = 7.1$ lb/hr

3. Unit No. 2 only - $W_a = 8.2$ lb/hr

b. Series operation.

$W_a = 5.1$ lb/hr

Flow through the units using the booster blower was not quantitatively determined because the ΔP range on the gages installed for this system was not sufficient to permit reading air flows greater than 8.6 lb/hr (sea-level operation). This was done intentionally to permit more accurate determination of flow in normal mode. When the blower is turned on the gages will peg, but will not be damaged.

Both units as received required the main-power switch to be on before the press-to-test switch would light all lights. This was changed so that press-to-test would check all lights without the power switch being on.

8.2.4.3 Unit Evaluation. As previously explained, limited testing was accomplished on the catalytic burners to evaluate oxidation characteristics as installed within the test bed. The burners were used primarily as required to support other system tests such as the CO₂ reduction unit or in integrated system tests with all or most of the systems operating.

Preliminary System Testing at 10 psia. All systems were operated in a 10-psia atmosphere in a test run 8 April 1965. The catalytic burner was operating to receive bleed gases from the CO₂ reduction unit at this time as well as from the test-bed atmosphere. The two burners were brought to operating temperature prior to the start of test. The units were then shut down and test conditions established. The burners were restarted and operated in parallel and lower-deck purge mode. The test-bed inlet air was supplied through a flex tube that was placed to withdraw air from over the reduction unit high-temperature package. This was done to attempt to alleviate contamination of the atmosphere from higher-than-desired leakage from the reduction unit.

Normal reduction-unit contaminants were detected in the catalytic-burner gas inlet with no trace of such contaminants in the gas discharge from the burners. Further indication of oxidation of contaminants was that the heaters did not come on again after

initial startup, although catalyst-bed discharge temperatures were in excess of 750° F during the time that reduction-unit bleed was supplied to the burners. Because of the required warmup period of these units, a study was initiated to try to define a procedure that might be established to allow quick warmup of a catalytic burner for emergency use. To assist in this evaluation, test data obtained during unit warmup were utilized. Two separate runs of each burner were made that cover operation in boost mode with both heater elements energized and with only a single heater element energized. The system mode was parallel for both runs. Results of these runs are presented in Figures 8.2-45 and 8.2-46 and Table 8.2-XXIII. Burner temperature recorded was that obtained downstream of the catalyst bed and displayed on the panel-mounted pyrometers. These temperatures were corrected from the calibration curve obtained from each pyrometer. These calibration curves are presented in the appendix. It is seen that the heating characteristic is essentially the same for either burner, for burner mode either high or normal. Warmup to 700° F in approximately 4 hours can be obtained with both heater elements energized. Although unit heat losses become significant as unit interior temperature increases, as a first approximation assume that the following expression is sufficient to 700° F.

$$dq/dt = mcp \, dT/dt$$

where

$$\begin{aligned} dq/dt &= \text{rate of heat input} \\ &= 854 \text{ Btu/hr for high} \\ &= 427 \text{ Btu/hr for normal} \end{aligned}$$

$$\begin{aligned} dT/dt &= \text{rate of temperature increase} \\ &= \frac{(700-70)}{4} = 630/4 = 157.5^\circ \text{F/hr for high mode} \end{aligned}$$

$$\begin{aligned} mcp &= \text{equivalent mass times specific heat} \\ &= \text{Btu}/^\circ \text{F. This defines the required heat input to achieve a} \\ &\quad \text{specified increase in catalyst bed discharge temperature.} \\ &\quad \text{From the data of Figures 8.2-44 and 8.2-45.} \end{aligned}$$

$$mcp = \frac{dq/dt}{dT/dt} = 854/157.5 = 5.42 \text{ Btu}/^\circ \text{F}$$

The total heat input required is thus equal to 3416 Btu/hr or the equivalent of 1 kilowatt. The rate at which the heat is introduced depends upon the maximum time allowable for warmup. Power requirements for achieving warmup times in the range necessary to permit emergency use (estimated maximum practical allowable time is 15 minutes) would be in excess of 15 kilowatts. This high power is not practical and should eliminate any attempt to heat the units quickly from internal heaters.

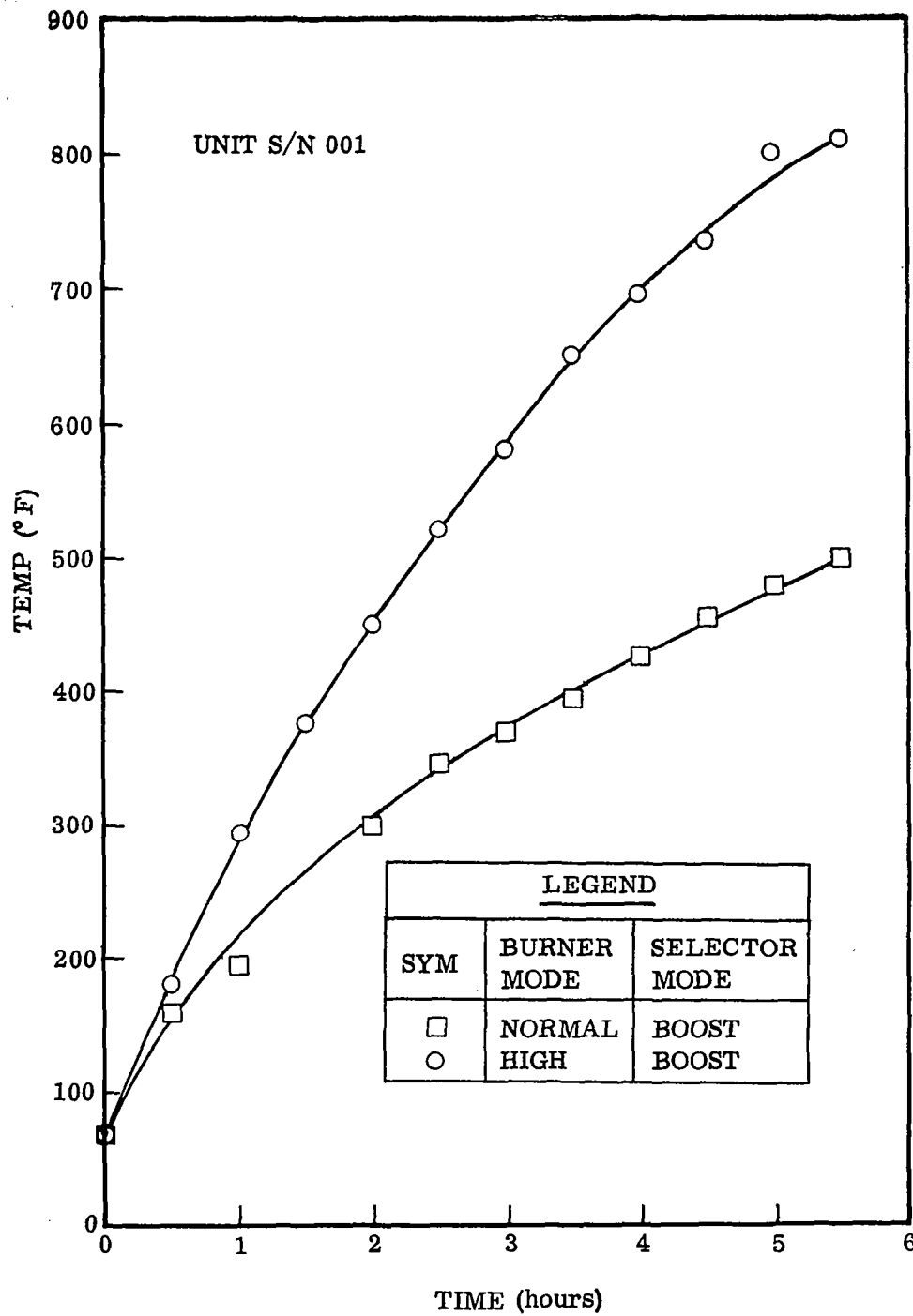


Figure 8.2-45. Catalytic Burner Heating Characteristic, Unit S/N 001

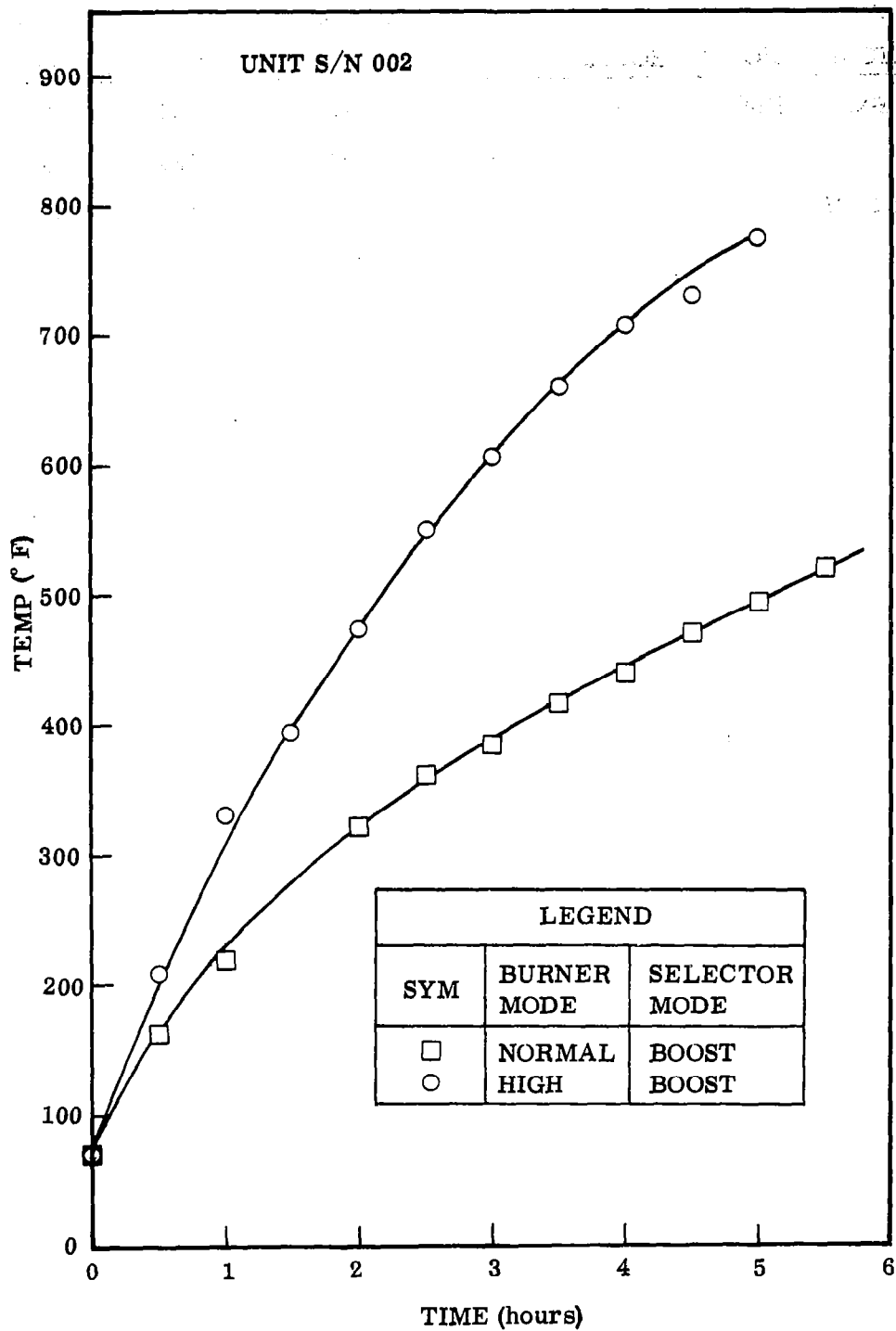


Figure 8.2-46. Catalytic Burner Heating Characteristic, Unit S/N 002

Table 8.2-XXIII. Catalytic Burner Heating Tests

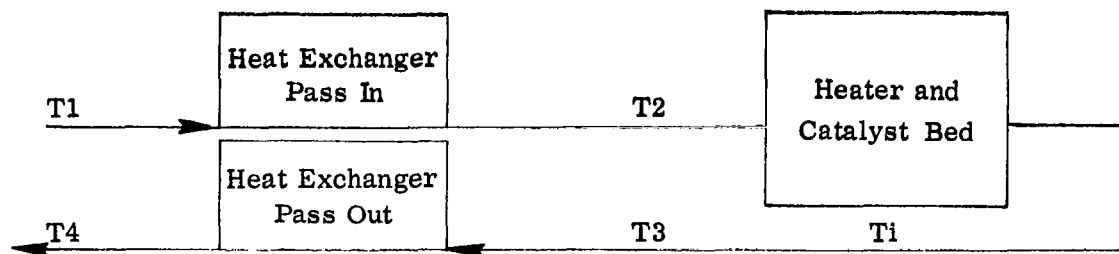
<u>SELECT BURNER TIME</u>				<u>UNIT NO. 1</u>		<u>UNIT NO. 2</u>	
<u>RUN</u>	<u>MODE</u>	<u>MODE</u>	<u>HOURS</u>	<u>T-°F</u>	<u>T corr.-°F</u>	<u>T-°F</u>	<u>T corr.-°F</u>
1	Boost	High	0	85	70	165	70
			0.5	190	182	290	208
			1.0	300	295	400	330
			1.5	380	376	480	395
			2.0	450	450	530	473
			2.5	520	520	600	550
			3.0	580	583	650	606
			3.5	645	650	700	660
			4.0	690	695	740	708
			4.5	730	736	760	730
			5.0	790	800	800	775
			5.5	800	810	-	-
2	Boost	Normal	0	90	-	160	-
			0.5	170	162	250	163
			1.0	205	197	300	220
			2.0	305	300	395	322
			2.5	350	345	430	362
			3.0	375	370	450	384
			3.5	400	395	480	417
			4.0	430	427	500	440
			4.5	455	455	530	472
			5.0	480	480	550	495
			5.5	500	500	575	522

Parallel Operation

Parallel Operation

Because of the high-effectiveness regenerative heat exchanger utilized in this unit, adding heat to the incoming air stream to provide interior heating is also impractical. This is illustrated as follows.

The geometry gives the following system:



$$\epsilon = \frac{T1 - T2}{T1 - T3}$$

or

$$\epsilon = \frac{T4 - T3}{T1 - T3}$$

$$\therefore T1 - T2 = T4 - T3,$$

which simply indicates that the heat introduced into the system is merely exchanged across the regenerative heat exchanger and rejected without significantly affecting interior temperature. This is, of course, precisely the function of any regenerative heat exchanger.

From the foregoing, it was concluded that both catalytic burners should be on during system operation. This then provides redundancy in the event of failure of one unit.

No significant additional testing of these units was accomplished until the final demonstration test runs.

8.2.4.4 Final Demonstration Test. Both catalytic burners were run during the integrated system demonstration test of 13 July 1965. A palladium catalyst was in S/N 001 and the MRD proprietary catalyst was in S/N 002. This system was started well in advance of the system test because it required a 4- to 6-hour warmup to achieve a temperature in the range for thermostatic control. An interlock between this unit and the reduction unit was installed prior to these tests. The purpose of

the interlock is to prevent purging of the reduction unit through the catalytic burner before the burner system is operational and at required temperature. A slight overlap of the low-temperature switch and the burner-control thermostat existed on S/N 002 and required adjustment prior to test to allow the interlock to function without interference through the normal thermostatically controlled temperature band. The boost mode of burner operation was employed for these tests to demonstrate blower operation as well as burner operation. The burners were connected in parallel and each had a flow of approximately 5.3 lb/hr throughout the test.

The temperature downstream of the catalyst bed, which is the temperature the control thermostat senses, is shown versus time in Figure 8.2-47. The cyclic nature of the control is evident. The frequency of thermostat operation is seen to be somewhat in excess of once per hour. The controlled temperature band of 710°F to 780°F for S/N 001 and 700°F to 740°F for S/N 002 is considered satisfactory since the specification value for control band was 700°F to 800°F.

Data recorded during these tests is contained in Table 8.2-XXIV.

No bleed from the reduction unit was passed to the burners during the first half of the test, but some bleed was utilized during about the last hour of test. Gas-chromatography analysis showed no contaminant buildup from gases in the reduction system being released to the cabin, which indicates adequate oxidation through the burners.

Test of the burners was thus regarded as completely satisfactory with respect to performance, stability of operation, and control parameters.

8.3 WATER MANAGEMENT

8.3.1 SAI TESTS

8.3.1.1 Air Evaporation Units. The SAI tests were conducted at the Hamilton Standard Division of United Aircraft in October 1964. Unit No. 1 was functionally tested in a 24-hour urine process run with 20 hours at 10-psia and 4 hours at 14.7-psia ambient pressure. Of the 20 hours conducted at reduced pressure, 10 hours were operated with 83°F cooling-fluid inlet temperature and 10 hours at 55°F. A process rate of 1.30 lb/hr (0.5 lb/hr above the rate defined by the procurement specification) was attained for the higher coolant temperature and 1.42 lb/hr for the lower coolant temperature. A heat-balance diagram for each case is shown in Figure 8.3-1 and 8.3-2. The additional 4 hours conducted at sea-level pressure used the higher coolant temperature (83°F). The resulting process rate was 1.32 lb/hr. A heat-balance diagram for this case is shown on Figure 8.3-3. Recovery efficiency was determined to be ≥ 98 percent. A product water analysis for the three operating conditions is briefed in Table 8.3-I. Unit No. 2 was functionally tested in a 1-hour run to determine operability and process rate. There were 1.38 pounds of product water collected.

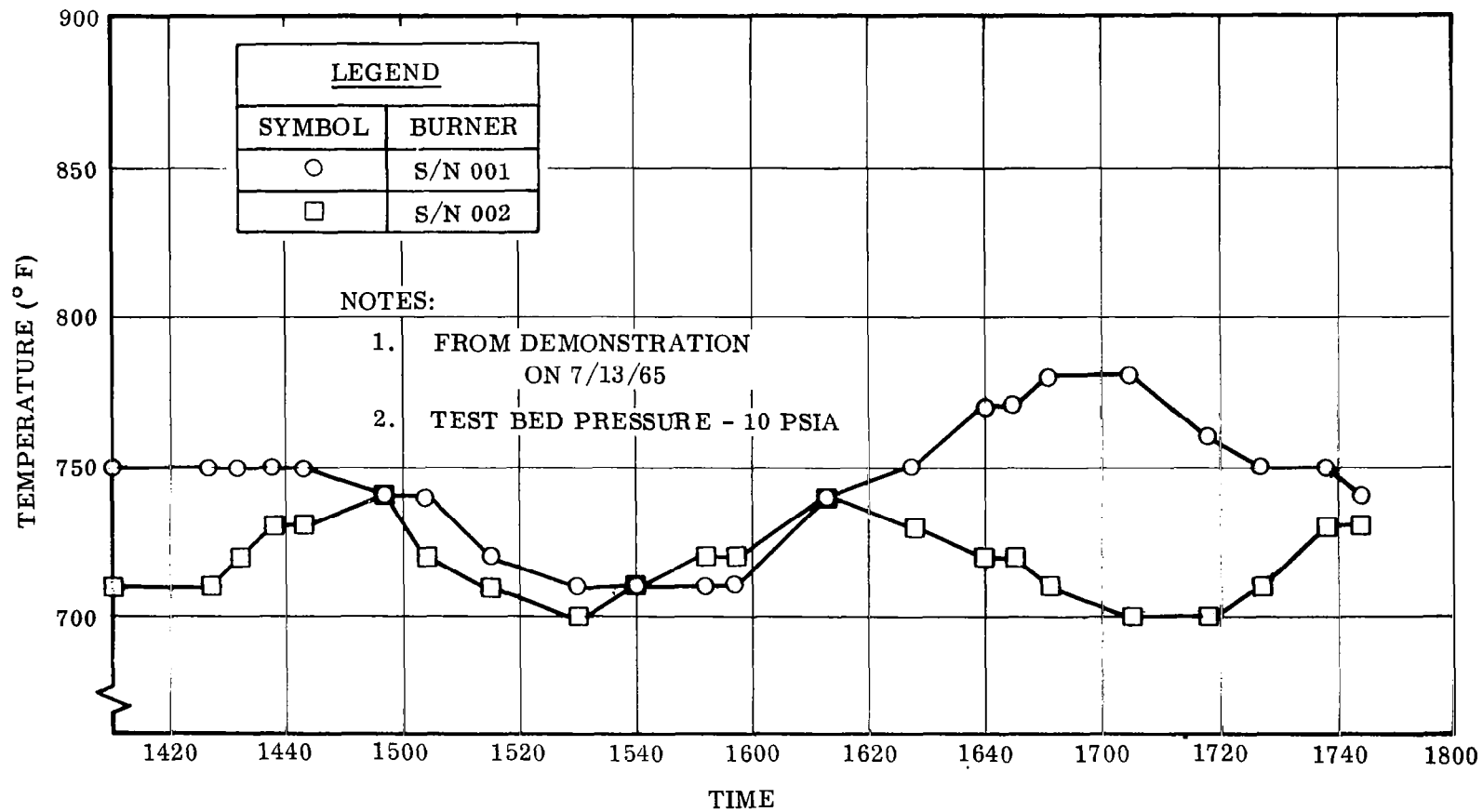


Figure 8.2-47. Catalytic Burner Temperature Profiles

Table 8.2-XXIV. Catalytic Burners Final Demonstration Test Data *

S/N 001		S/N 002	
T_1 ($^{\circ}$ F)	ΔP_1 (in. H_2O)	T_2 ($^{\circ}$ F)	ΔP_2 (in. H_2O)
750	0.29	710	0.36
750	0.30	710	0.29
750	0.30	720	0.29
750	0.30	730	0.29
750	0.30	730	0.29
740	0.30	740	0.29
740	0.30	720	0.29
720	0.30	710	0.29
710	0.31	700	0.29
710	0.31	710	0.29
710	0.31	720	0.29
710	0.31	720	0.29
740	0.31	740	0.29
750	0.30	730	0.29
770	0.30	720	0.29
770	0.31	720	0.30
780	0.30	710	0.30
780	0.30	700	0.30
760	0.30	700	0.30
750	0.31	710	0.29
750	0.31	730	0.29
740	0.31	730	0.29

*13 July 1965

Dry-down runs and unit inspection were performed on both units.

The major problem observed was the limitations with the water separators. Neither separator would pump against the required head and would stall unless water was pumped from the separator case. Properly functioning water separators that would meet specifications were to be provided at a later date.

8.3.1.2 Multifiltration Unit. The SAI tests were conducted at the Electric Boat Division of General Dynamics in August 1964. Three types of tests were conducted.

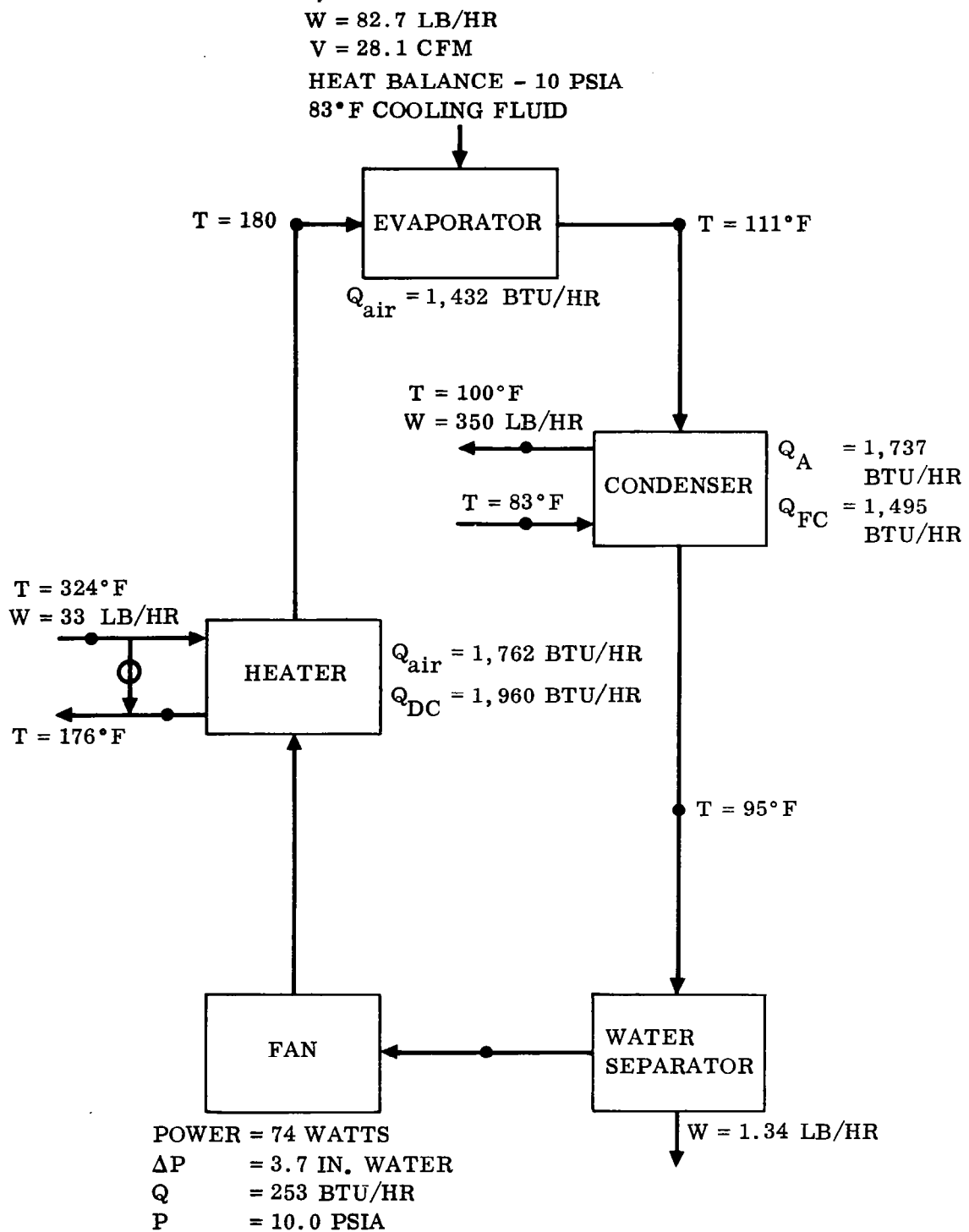


Figure 8.3-1. Air Evaporation Unit, Heat Balance = 10 psia, Cooling Fluid = 83°F

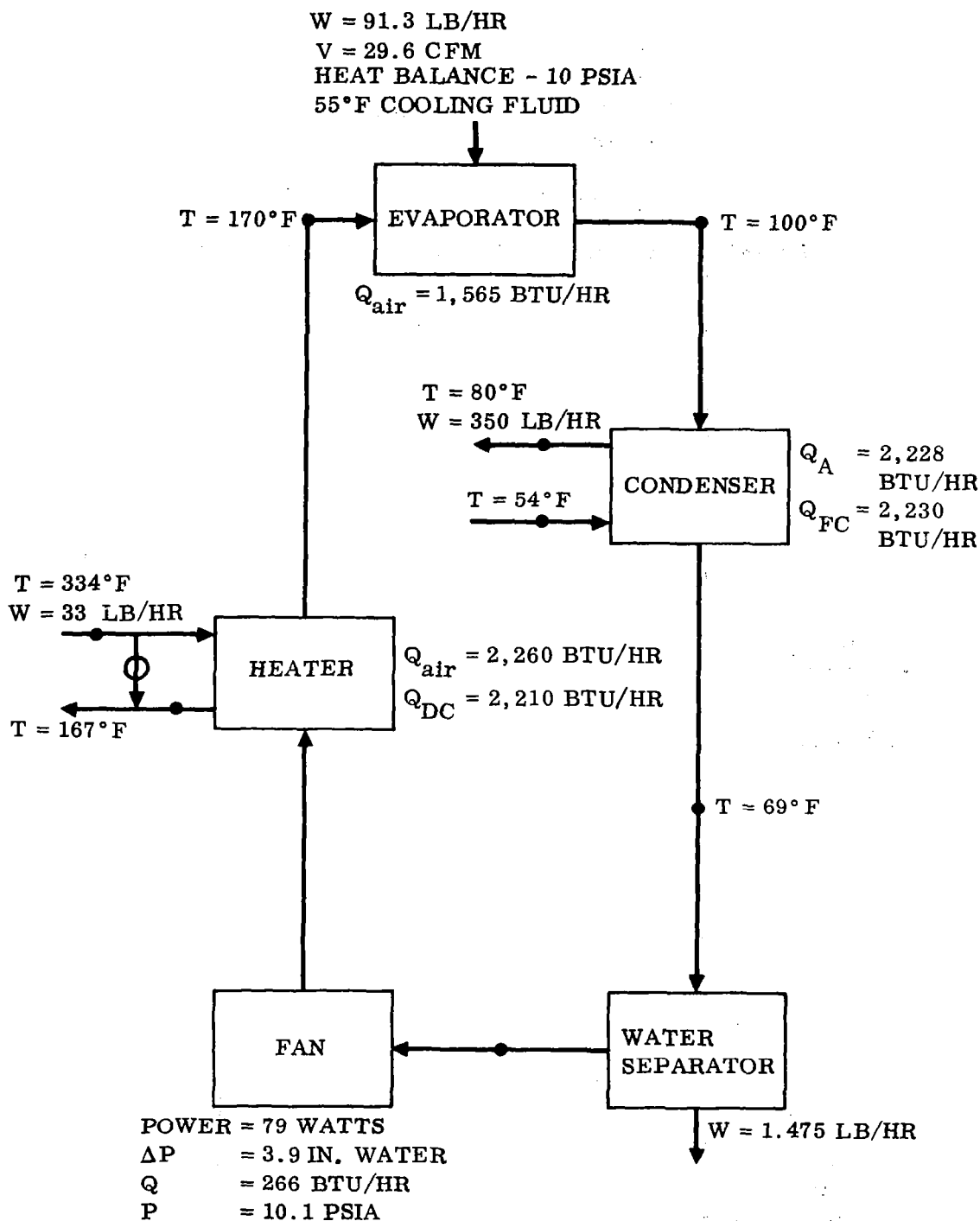


Figure 8.3-2. Air Evaporation Unit, Heat Balance = 10 psia, Cooling Fluid = 55°F

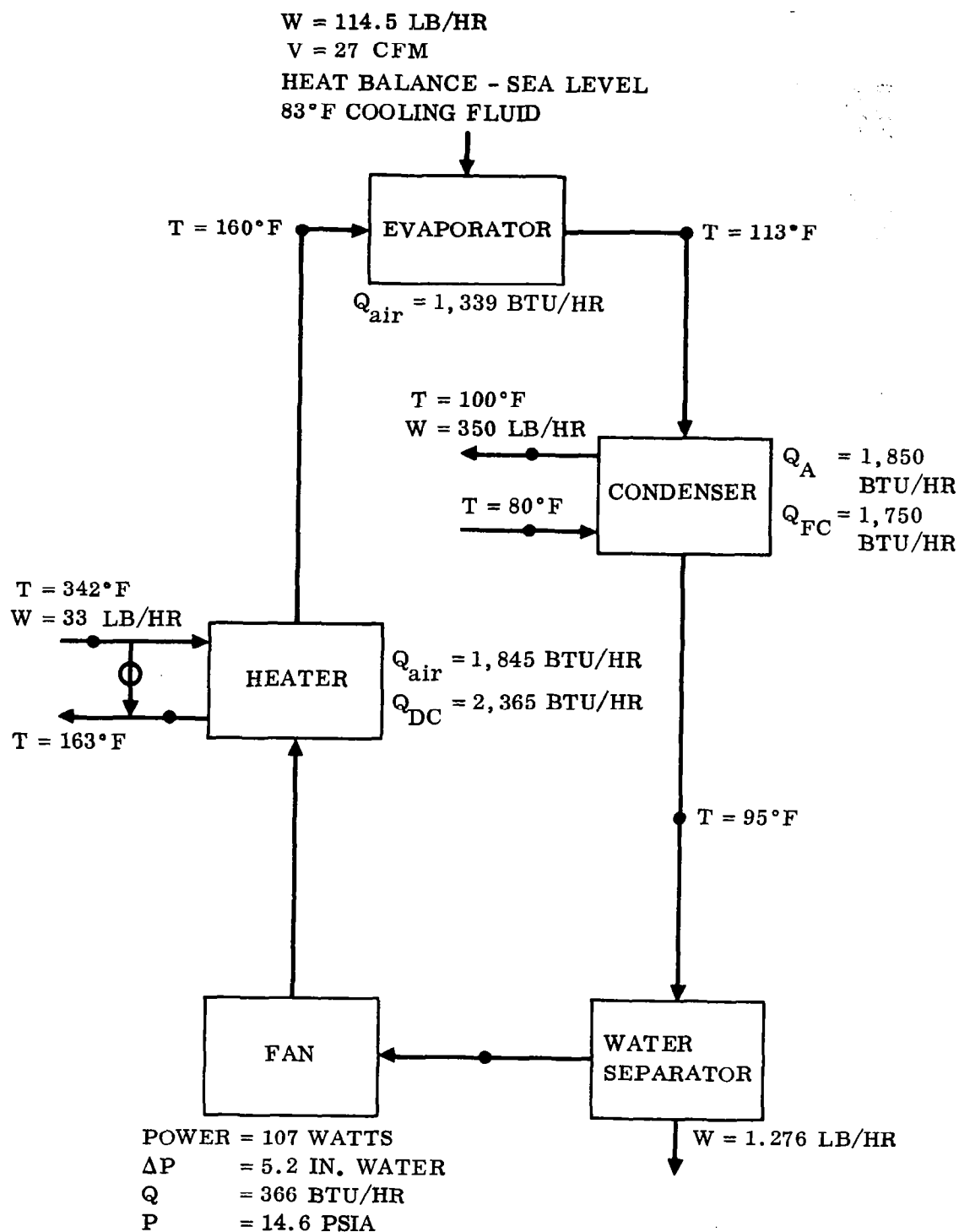


Figure 8.3-3. Air Evaporation Unit, Heat Balance = Sea Level, Cooling Fluid = 83°F

Table 8.3-I. Processed Water (Urine) Analysis

SPECIFICATION STANDARDS		CONDITION NO. 1 (10 psia, 83° F)		CONDITION NO. 2 (10 psia, 55° F)		CONDITION NO. 3 (14.7 psia, 83° F)
		SAMPLE 1	SAMPLE 2	SAMPLE 1	SAMPLE 2	
pH	6 - 8	4.2 ¹	4.9	4.9	5.9	5.9
Conductivity (max)	100 μ mho/cm	63.0	43.2	26.2	43.2	55.4
Total solids (max)	100 ppm	48	33	28	29	29
Ammonia	<20 ppm	4.0	2.1	3.1	4.5	7.0
Chlorine	<10 ppm	<0.5	<0.5	<0.5	<0.5	1.0
Sulfate	<10 ppm	<0.4	<0.4	<0.4	<0.4	<0.4
Urea	<0.5 ppm	0	0	0	0	0
Bacteria	</colony/ml	<0.022 ²	<0.022	<0.022	<0.022	<0.022
Turbidity	None visible	1.0 ³	0	0	0	0
Color	None observable	2.0 ⁴	2.0	1.0	1.0	2.0
Odor	No unpleasantness	Faint rubber ⁵	Same	Same	Same	Same
Taste	No unpleasantness					

1 Insufficient charcoal cleansing considered to have produced the low pH readings (acid).

2 Coloform "count" only, most probable value.

3 Units; 5 allowable by U.S. Public Health Service.

4 Units; 15 allowable by U.S. Public Health Service.

5 Thought to be associated with sample bottle materials.

Type A was an endurance run on a non-deliverable laboratory model to demonstrate effectiveness and life, Type B was a full scale performance run on the deliverable unit but employing a set of reclaimable laboratory type canisters that were to be delivered as engineering test canisters following reconditioning, and Type C, which was run on the complete deliverable unit to demonstrate equipment integrity. The latter was run on laboratory distilled water while the other two were run on a blend of humidity condensates collected from various sources including a submarine atmosphere.

Bacteria-filter-cartridge rupture problems were encountered in both Type A and B tests. Tighter cartridge inspection was initiated for subsequent test articles and the deliverable items.

A single test run in Type A (laboratory model) ruptured the bacteria filter after processing slightly in excess of 150 percent of the specified quantity of condensate blend.

Test Run No. 1 in Type B (recoverable canisters) ruptured after processing slightly more than 120 percent of specified capacity. Test Run No. 2, conducted with a new cartridge, was terminated at the 120-percent capacity point with no filter rupture experienced.

A single test run (Type C) was conducted on the deliverable system during which approximately 16 percent of capacity was processed.

The measurement values of these runs are summarized in Table 8.3-II.

8.3.2 CONVAIR FUNCTIONAL CHECKOUT. Checkout of the various components of the installed water management subsystem was divided into three functional test groupings: water-transfer and storage circuits, chemical-treatment circuits, and evaporation units. Except for plumbing and electrical continuity checks, no tests were conducted on the multifiltration unit following installation in the water management subsystem. This decision was based on the assumption that little if any significant information could be obtained beyond that derived from the SAI due to its inherently low degree of interaction with other LSS functions, its passive operating state, and the expendable nature of its components.

8.3.2.1 Water Transfer and Storage

a. Objectives.

1. Demonstrate continuity and integrity of plumbing, correctness of valve porting, proper orientation of valve position indicators, and proper circuit placarding.
2. Determine approximate batch-transfer rates.

Table 8.3-II. Humidity Condensate

MEASUREMENT	LABORATORY MODEL	RECOVERABLE CANISTERS		DELIVERED UNIT
pH	6.7	6.3	-	6.9
Conductivity (μ mho/cm)	<5.0	<5.0	<3.0	<2.0
Total solids (ppm)	13	<20	-	7
Ammonia	None	-	-	-
Taste	None	None	-	None
Odor	None	None	-	None
Turbidity	Slight	None	None	None
Color	None	None	None	None
Bacteria colonies/ml	-	<3	<1	<1

3. Isolate and correct circuit errors.
 4. Test the procedures developed in Operational Description, General Dynamics Convair Report 64-26219, and correct deficiencies.
- b. Methods. Batch transfer (distilled water) from tank-to-tank simulating the various modes of operation (normal, backup, emergency) of the subsystem (recovery units bypassed by temporary test circuit). Actual operational sequences used employing the designated liquid and pressurization valve positions.
- c. Results.
1. All transfer requirements could be met.
 2. Transfer rates are approximately 8 pounds per minute.

8.3.2.2 Chemical Treatment

- a. Objectives.
1. Demonstrate the continuity, integrity, and proper operation of plumbing and components for the pretreatment and post treatment circuits.
 2. Determine pretreatment injector quantities.
 3. Identify and correct problems encountered.
- b. Methods.
1. Pretreatment injectors operated against both pressurized and unpressurized dilution tanks.
 2. Change in liquid volume (distilled water) in injector inlet supply taken as injector displacement (results obtained from employing a burette and by actual weight change of the chemical-storage tank were compared).
 3. Syringe (50-cc graduate) withdrawal from post-treatment chemical (BAC) storage tank and injection into charged-pressurized water storage tank.
- c. Results.
1. Average pretreatment injection volumes are approximately 6 cc per stroke.
 2. Variability existing between injections and inability to monitor injection quantities may prove to be a problem.
 3. Post-treatment injection techniques are satisfactory.

8.3.2.3 Evaporation Units. Functional checkout of the evaporation units was conducted under two modes of operation. One mode did not involve water processing. The other mode did.

Nonprocessing-Mode Test Runs

a. Objectives.

1. Demonstrate the operability of air-loop and thermal circuit components.
2. Check out air-loop and thermal circuit controls and instrumentation.

b. Methods.

1. Units to be operated singly and simultaneously.
2. Thermal circuits operating.
3. Air-loop bypass installed around evaporator.

c. Results. Unit No. 1 (major demonstration unit at SAI) was found to be inoperative due to fan-motor failure caused by rotor-to-stator rust accumulation resulting from flooded conditions experienced at SAI. Also Unit No. 1 condenser failed, possibly from air-loop heating of the condenser with coolant trapped in circuit. Repair time of the unit limited its operation in this test phase. Thirty hours of test time were accumulated in this mode. Changes were made in the liquid thermal circuits to preclude valve-position error and to increase control stability. Rework was completed on both automatic air-loop evaporator inlet temperature controls. The auto temperature control was considered satisfactory in its final configuration.

Processing-Mode Test Runs

a. Objectives.

1. Demonstrate operability of all water-management components involved in normal process runs.
2. Check out all controls and instrumentation required for normal operation.
3. Determine process rates for various air-loop temperatures.

b. Method. Operate units in normal modes except that untreated distilled water is used for process input water.

c. Results.

1. Twenty-one hours were accumulated on Unit No. 2; Unit No. 1 inoperable due to condenser repair.
2. Further trimming of the air-loop evaporator inlet temperature control was required to effect stability.
3. Continued problems were encountered with the air/water separator with respect to stall and pumping capability.

8.3.3 PERFORMANCE EVALUATION

a. Objectives.

1. Evaluate the operability of the evaporation units and the associated waste water collection, pretreatment, storage, and transfer equipment, employing actual waste water.
2. Determine process rate from each unit operated separately and simultaneously.
3. Determine product water quality.

b. Methods.

1. Urine introduced through the waste management urinal in full simulation of operational use.
2. Waste wash water introduced through personal hygiene water separator.
3. Condensate pumped into collection circuit upstream of pretreatment dilution tank (DT-2).
4. Each unit operated separately and simultaneously with product water catch made from evaporation unit recycle circuit (upstream of water charcoal filter). Units operated at sea-level ambient pressures.

c. Results.

1. Process rates obtained from Unit No. 1 (wash water and condensate) ranged from 2 lb/hr to 3.5 lb/hr depending upon scheduled coolant flows (condenser temperatures).
2. Process rates obtained from Unit No. 2 ranged from 2.5 lb/hr to 1.3 lb/hr depending upon scheduled coolant flows.
3. Unit No. 1 continued to produce component problems especially with weak feed control and air/water separator.
4. Product water quality was characteristically higher for Unit No. 2 than Unit No. 1. Unit No. 1 often produced water with some turbidity and sweet odor. Product water conductivity and pH remained within limits throughout. Bacteria counts ranged from zero to "too numerous to count" but averaged around 1000 colonies/ml (no bacteria of coliform group present).
5. Wash water containing 500 ppm BAC produced excessive foaming in the personal hygiene water separator. Reduction to 50 ppm was made.
6. For potable water, BAC at 10 ppm found to be acceptable to taste but unacceptable to prevent growth of bacteria, 50 ppm is marginal for both aspects, and 100 ppm prevents bacteria growth but is unacceptable to taste.

7. Untreated potable water drawn from the hot-water heater was found to be bacteria free.
8. Automatic evaporator inlet temperature control was found to be workable (Figure 8.3-4) but required operator attention for adjustment.
9. Air/water separators continued to produce problems.

8.3.4 FINAL DEMONSTRATION TEST

a. Objectives.

1. Demonstrate the mechanical integrity of all aspects of the water management subsystem including collection, transport, chemical treatment, and storage.
2. Demonstrate satisfactory recovery of potable water from waste water by both evaporation units.
3. Demonstrate the effectiveness of all significant changes made as a result of problems encountered in the subsystem performance evaluation tests.

b. Methods.

1. CT-1 charged with pretreated humidity condensate and waste wash water. CT-3 charged with pretreated urine.
2. Both units operated simultaneously at both sea-level and 10-psi ambient pressure.

c. Results.

1. All collection and transport circuits performed properly.
2. Both units operated satisfactorily at both sea level and at 10 psia.
3. Product water quality was satisfactory, clear, odorless, no objectional taste, conductivity and pH within limits.
4. No problems were encountered with air/water separators, wick-feed control, temperature control, or other subsystem components.
5. Process rates were within requirements.

The following operating conditions were typical of the test data (see data sheet, Table 8.3-III) recorded during the 10-psia ambient pressure run.

Table 8.3-III. Water Management System; Water Recovery Units

TIME	EVAPORATION		DC-331		COOLING		COND.	AIR	CONDUCTIVITY	SUPPLY	WICK	HEATING FLOW		LIQ/GAS	COOLING	CONDITIONS AND REMARKS	
	TEMP (°F)	TEMP (°F)	TEMP (°F)	TEMP (°F)	TEMP (°F)	TEMP (°F)	ΔP (in. H ₂ O)	ΔP (in. H ₂ O)	TANK LEVEL	FEED TEMP (°F)	H-102 F (in. H ₂ O)	H-103 F (in. H ₂ O)	SET (rpm)	FLOW K-103 F (in. H ₂ O)			
UNIT NO. 1																	
1155	140		80	355	190	42	70	55	0.3+	80 - 30	3.9	100	11	7	2100	7	15-psi ambient start at 1130 hours.
1225	135		80	346	185	35	66	48	0.5+	8	3.9	101	11	7	2100	7	Process start 1150 hours (1230 hours shutdown).
1435	136		75	351	204	30	60	42	0.42	8	3.9	100	10	7	1800	7	10-psi start 1420 hours (purged); catch start 1430 hours.
1505	160		80	351	206	34	64	45	0.42	5	3.9	100	11	7.4	1785	6.7	Catch at 1510 hours = 580 gm.
1535	162		82	353	208	34	65	46	0.43	5	3.9	101	10.4	7.5	1830	6.6	
1605	162		84	355	208	35	66	46	0.43	5	3.9	115	10.5	7.6	1800	6.5	Catch at 1610 hours = 1440 gm, batch trip.
1635	157		85	354	205	32	64	44	0.43	5	2.4	104	10	7	1850	6.8	
1658	167		86	355	211	34	67	45	0.44	5	2.4	114	13	4	1800	6.8	Catch at 1700 hours = 2195 gm.
1727	170		87	357	214	32	66	45	0.44	5	1.7	110	11.5	8.5	1850	6.8	Batch trip at 1710 hours.
1745			Cold shutdown														Catch at 1745 hours = 2860 gm. Shutdown 1745 hours.
UNIT NO. 2																	
137			87	355	191	70	84	78	0.4	80 - 45	3.8	100	11.5	8.5	2340	7	15-psi ambient start at 1130 hours.
1230	137		93	346	190	65	84	76	0.4	22	3.8	100	11.5	8.5	2750 2250		Process start at 1150 hours.
1430	144		81	350	200	58	73	65	0.3	20	3.8	100	10.5	7.2	2175 2000	7	10-psi start at 1415 hours (purge); catch start at 1425 hours.
1500	154		90	350	205	63	81	73	0.3	17	3.8	100	11	7.5	1870 1950	6.7	Catch at 1500 hours = 380 gm.
1530	157		95	350	209	65	83	74	0.3	16	3.8	100	10.9	7.6	1980	6.5	
1600	156		96	351	207	65	83	74	0.3	16	3.8	100	10.5	7.6	2150 1950	6.5	Catch at 1615 hours = 980 gm.
1630	154		97	351	205	62	81	72	0.3	16	3.8	109	10	7	1980	6.8	
1655	160		100	350	210	64	84	75	0.3	17	3.4	100	13	6.9	2250 2100	6.9	Catch at 1700 hours = 1370 gm.
1724	160		100	354	210	64	83	75	0.3	16	3.4	102	11.5	6.8	2750	6.8	Trip at 1738 hours.
1745			Cold shutdown														Catch at 1745 hours = 1790 gm. Shutdown at 1745 hours.

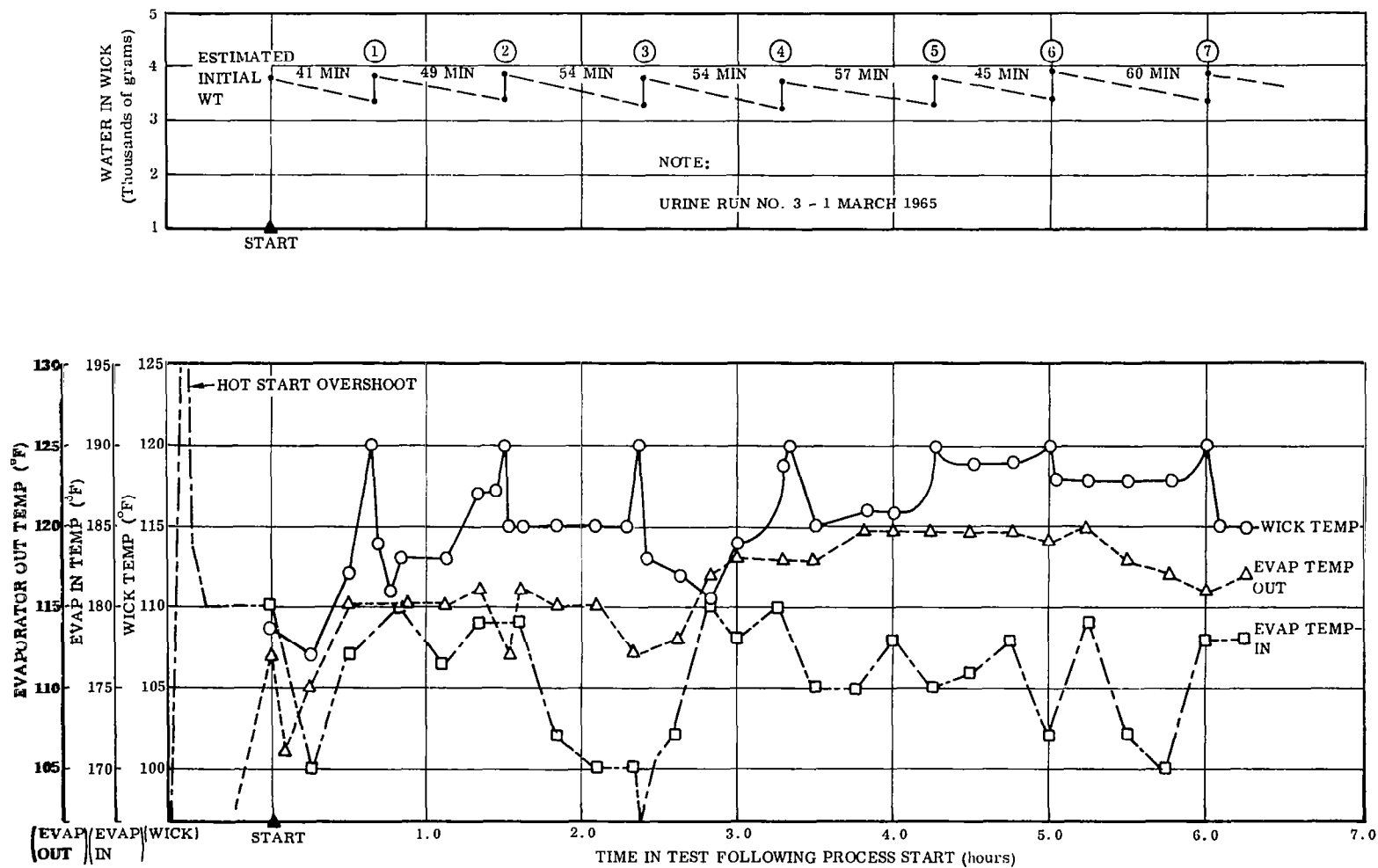


Figure 8.3-4. Water Recovery Unit No. 2 Test Data

	<u>Unit No. 1</u>	<u>Unit No. 2</u>
Evaporator Inlet Temperature, °F	162	157
Evaporator Outlet Temperature, °F	82	95
Process Heat Inlet Temperature	354	350
Process Heat Outlet Temperature	207	207
Process Coolant Inlet Temperature	34	65
Process Coolant Outlet Temperature	65	84
Condenser Outlet Temperature	45	74
Air Flow, lb/hr	105	96
Conductivity, μ mhos/cm	< 5	16
Process Heating Fluid Flow, lb/hr	50	35
Coolant Flow, lb/hr	125	(same fluid)
Air/Water Separator Speed, rpm	1825	2100
Process Rate, lb/hr	1.95	1.2

Product waters were clear, odorless, and possessed no objectionable taste.

8.4 WASTE MANAGEMENT

8.4.1 SAI TESTS. Source acceptance testing was held at the MRD Division of General American Transportation Corporation during October 1964. Three feces drying cycles of 16, 20, and 24 hours each were completed with moisture removal of 76 percent, 87 percent, and 94 percent respectively. Feces and urine collection were demonstrated. Liquid/gas separator output attained a maximum of 18 lb/hr (approximately) at slightly over 5 psig and 5 lb/hr (approximately) at slightly less than 7 psig. Disassembly inspection following functional test indicated no deterioration with the feces-collection and drying functions but some corrosion was evidenced internally with the liquid/gas separator.

The major problems observed were associated with:

- a. Liquid/gas separator performance evidenced by excessive vibration, inconsistent flow/pressure characteristics, and intermittent loss of separation effectiveness. Additionally, internal corrosion appeared as a potentially unsolved problem.
- b. Excessive surface temperatures of various components and assembly panels.
- c. Potential for odor emission to the cabin during feces transfer following drying.

8.4.2 CONVAIR FUNCTIONAL CHECKOUT. Functional checkout of the waste management subsystem was conducted to assure that all functions affected by the installation into the LSS were operating properly and that no unsatisfactory conditions existed. A series of tests were run to:

- a. Assess the temperature distribution across the process heat circuit, the dryers, and the assembly surface temperatures.
- b. Determine the integrity of the dryer vacuum circuit.
- c. Check the operation of the subsystem controls and the accuracy of the installed instrumentation.
- d. Check the operation of the urine collector and transport.

Feces dryer circuits were found to be satisfactory. However, assembly surface temperatures were considered to be excessive and drying temperatures appeared to be marginal at best. Figure 8.4-1 illustrates vacuum-circuit integrity while Figure 8.4-2 shows typical circuit temperatures. Operation of the urinal demonstrated that excessive vibration was both a potential material and accoustical problem. In addition, start-up problems were experienced after extended periods of inactivity.

8.4.3 PERFORMANCE EVALUATION. The performance evaluation was conducted to determine the effectiveness of the unit with respect to both its feces-drying function and urine collection/transport. The subsystem configuration was unchanged from that which had completed the functional checkout, although a marginal performance capability was suspected.

Simulated fecal matter, prepared by mixing dried dog food and water, was employed for these tests. This conventional simulation was obtained by an approximate weight-mixing ratio of one part dry meal to three parts water. A quantity equivalent to the specified four-man daily product was divided equally and placed in four collection bags and in turn placed in a single drying bag and inserted in the right-hand dryer. Figure 8.4-3 is a temperature history and Figure 8.4-4 shows the actual weight loss versus test time. A removal effectiveness of 95.5 percent was achieved in the 23-hour test.

A decision was made to correct as many liquid/gas separator problems as possible prior to completing this phase of test. Changes were made to reduce vibration, improve pumping characteristics, increase available torque, and reduce internal corrosion.

Excessive assembly surface temperatures combined with the apparent requirement to schedule higher process heat inlet temperatures, approximately 300° F versus an expected system operating value of less than 200° F, dictated that steps be taken to increase process heat inlet temperatures and to decrease conductive and radiative heat losses within the assembly.

Handling problems and apparent feces compacting resulting in uneven drying suggested that a removable metal basket and collector bag separator be added to the dryer assembly.

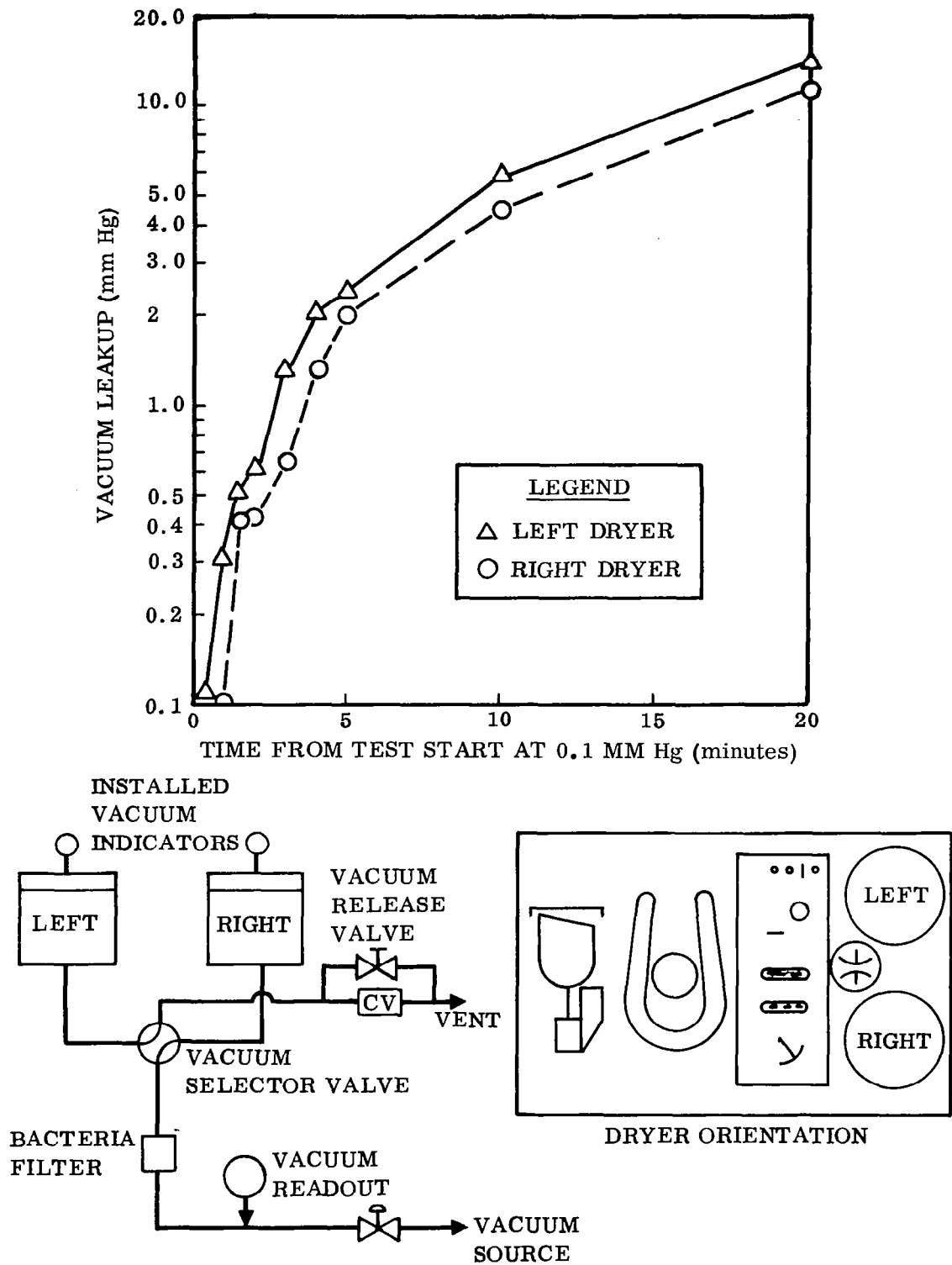
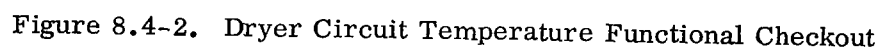


Figure 8.4-1. Vacuum Leakup Test



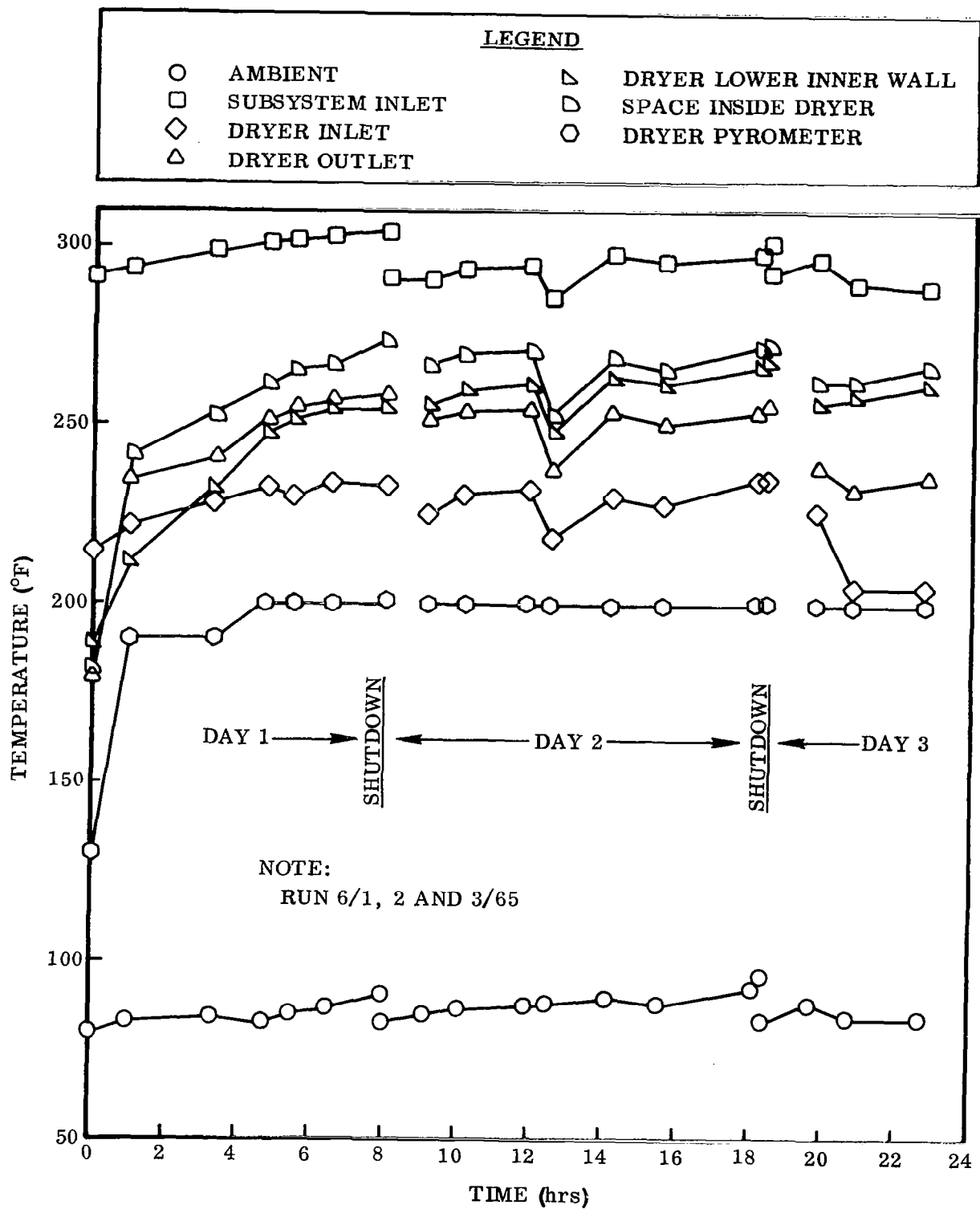
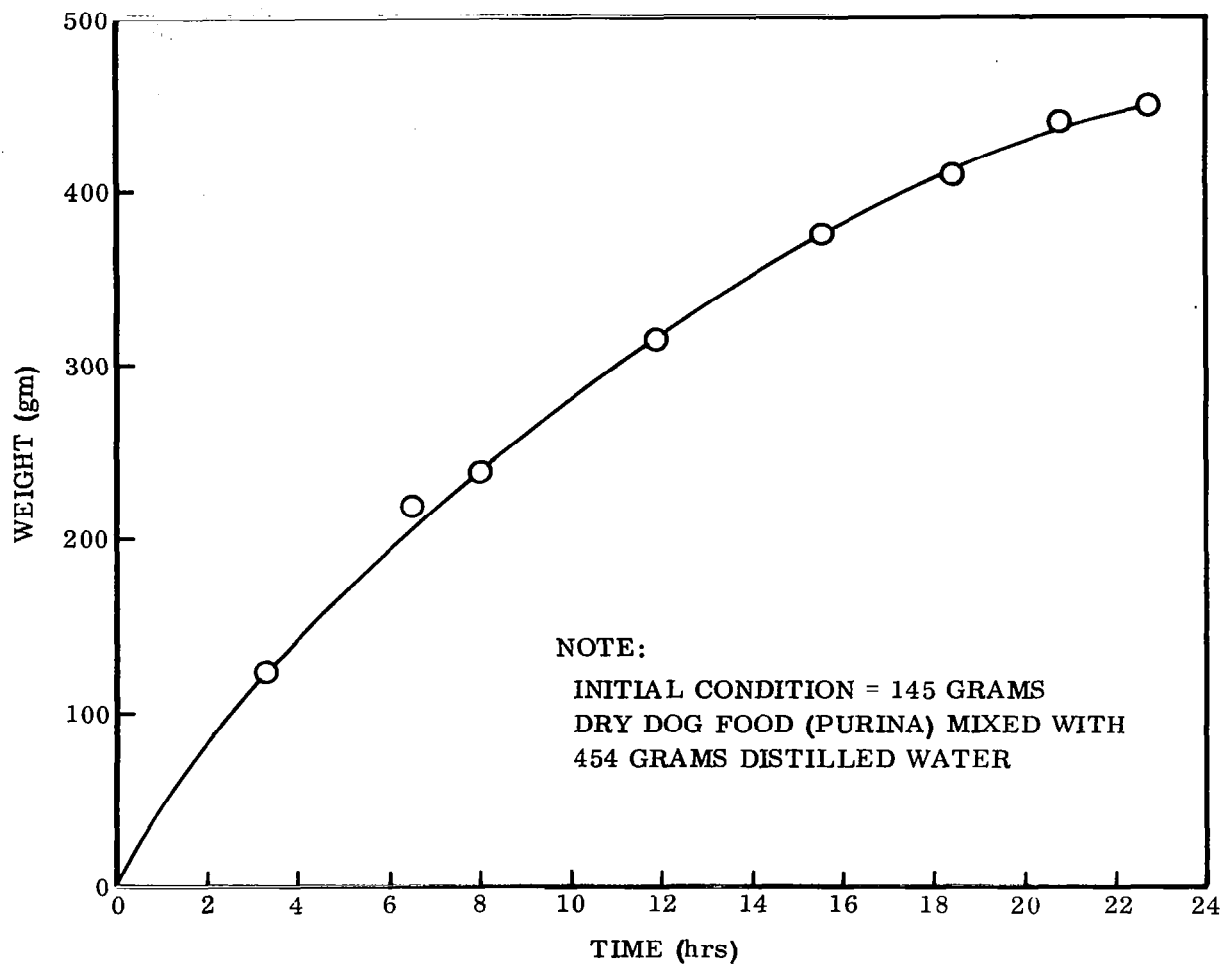


Figure 8.4-3. Feces Dryer Temperature History



8.4-4

Figure 8.4-4. Feces Dryer, Specimen Weight Loss Versus Time

8.4.4 FINAL DEMONSTRATION TESTS. Prior to initiating integrated system tests the assembly was reinsulated and the process heat circuit within the assembly simplified. Doing so significantly decreased the surface temperatures and reduced the heat transfer to the cabin. In addition, the system process heat circuit (see section on Thermal Control Process Heat Circuit) was altered to provide a higher fluid temperature. The test run was similar to the performance evaluation run previously described. The weight-loss history was essentially identical to that previously attained during the performance-evaluation tests. Drying effectiveness of at least 95 percent was attained. Process heat circuit changes produced an indicated dryer temperature (T_7) of 240° F at an ambient of 10 psia for process heat flows slightly less than those employed during performance evaluation. Heat losses to the cabin were significantly decreased. The drying basket and separator installed to minimize handling problems and uneven drying appeared successful.

8.5 PERSONAL HYGIENE

8.5.1 SAI TESTS. The SAI tests for the water heater were conducted at the Whirlpool Corporation in conjunction with testing of the food management subsystem. Problems were encountered with temperature control requiring control-valve alterations. Final tests were conducted per agreement without Convair and NASA/LRC monitoring and were considered satisfactory. Water temperatures were held at specified values of 120-130° F.

The air/water separator SAI tests were conducted at MRD Division of United Transportation Corporation in conjunction with the waste management unit test. This separator, being identical to that employed for urine collection and transport, experienced identical problems: excessive vibration, inconsistent performance, marginal effectiveness, and internal corrosion. Rework reduced the problems to a level considered acceptable for delivery to the next level of development.

8.5.2 CONVAIR FUNCTIONAL CHECKOUT. Functional checkout tests were performed to assure that:

- a. Water could be successfully delivered to the water-heater sponge squeezer from the water management subsystem.
- b. The sponge squeezer could be effectively operated by the crewman.
- c. Water temperatures could be attained.
- d. The air/water separator could operate adequately.

During the functional-checkout phase, previously selected stainless-steel bearings were installed in the air/water separator to minimize the continuing bearing damage and excessive drag. The separator, although producing vibration and installation noise somewhat above a desirable level, operated satisfactorily to transport water to the water

management collection tank. As a result of these tests, a decision was made to rework the air/water separation in conjunction with the separator of the waste management subsystem to reduce vibration and increase performance. The details are covered in General Dynamics Convair Report 64-26231.

8.5.3 PERFORMANCE EVALUATION. Performance-evaluation tests were conducted to determine:

- a. The capability of the water heater to maintain the specified temperature range during normal crew demands.
- b. The results of rework to the air/water separator.

As a result of tests that established water draw-off rates consistent with those used by crew bathing, it was determined that the water-heater temperature controls required alteration. Specifically, the overtemperature cutoff switch was designed to actuate at a temperature above the steady-state control range of the temperature control (process heat flow control), but well within its characteristic overshoot resulting from a maximum reheat rate signal. This setting caused inadvertent shutdown of the heater. Correction was accomplished by substituting a higher overtemperature cutoff set point. Heater capacity and temperature control was shown to be adequate.

Rework of the air/water separator reduced vibration and improved pumping characteristics.

8.5.4 FINAL DEMONSTRATION TESTS. Demonstration tests of the personal hygiene subsystem interfaced with the demonstration of the water management subsystem collection functions. Qualitative evaluation of the demonstrated operation of the equipment components determined that the subsystem was performing satisfactorily.

8.6 FOOD MANAGEMENT

8.6.1 SAI TESTS. Source acceptance testing was conducted at the Whirlpool Corporation in October 1964. The principal concern, other than the quality inspections of equipment, was with the operation of the food preparation console.

Tests were conducted that measured the accuracy of the water metering devices and the capacities of the heater and cooler with respect to providing representative quantities of water within the specified temperature ranges and to repeat these draws within representative times.

During the course of the testing, the water-temperature controller (senses water temperature, controls process heat flow) was changed from a bypass (parallel controller) to a heater inlet control (series control) with a bypass load valve. The water heater held temperatures above 160°F while the cooler held temperatures below 45°F

during the representative meal preparation draws. Although heater temperatures were slightly below that specified, the unit was determined acceptable.

8.6.2 CONVAIR FUNCTIONAL CHECKOUT. Functional checkout of the food management subsystem was restricted to checkout of the food preparation console hot and cold water circuits as installed in the test bed. Water metering was determined satisfactory indicating proper interface with the water management subsystem as well as continued operation of the metering circuit. Water temperatures were satisfactory as indicated by the panel-installed, hot-water pyrometer and apparent temperature of the cold-water draw. The water heater temperature control was determined to be operative.

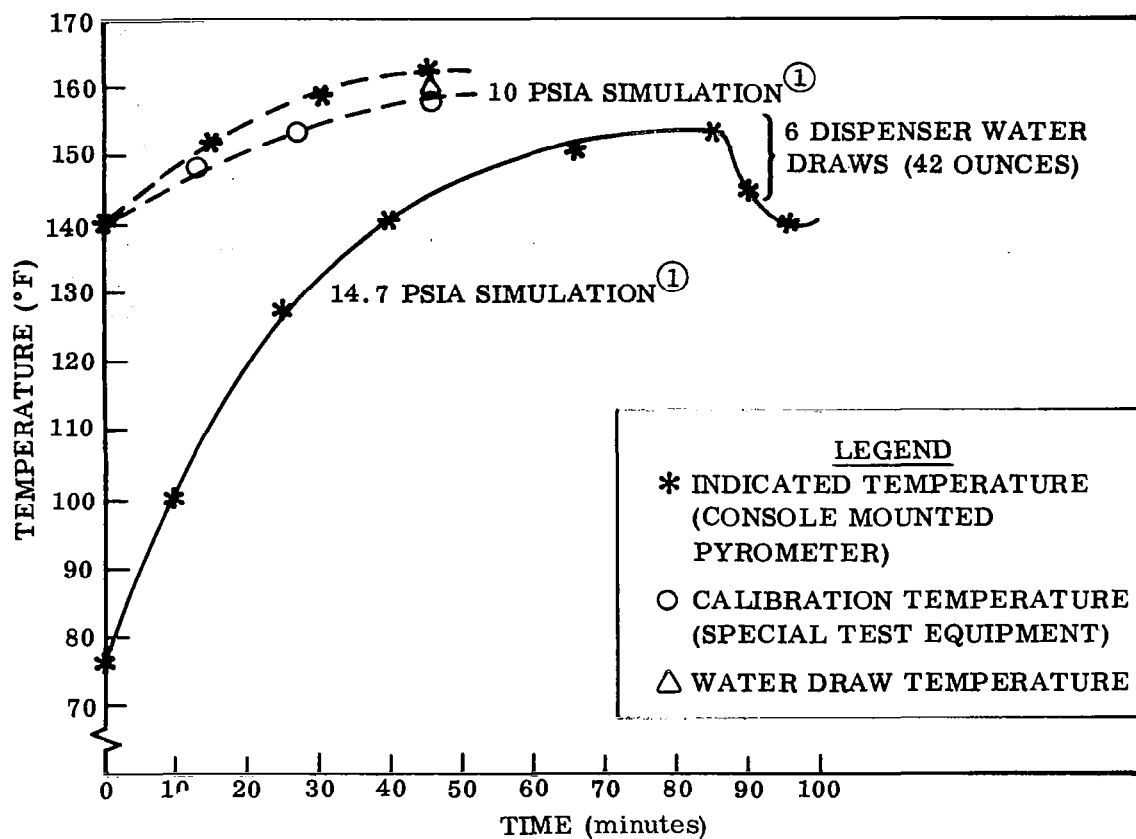
8.6.3 PERFORMANCE EVALUATION. Performance-evaluation tests were conducted to determine the capability of the food preparation console and food serving functions to provide satisfactory meals. Parameters considered important to the determinations were:

- a. Water heater warmup rates.
- b. Water heater capacity as reflected by temperature drop during reconstitution water draw.
- c. Comparison of indicated water temperatures: panel-mounted pyrometer readings with temperatures of both the water draw and a "calibrating" heater temperature readout.
- d. Consensus reactions of the test crew to:
 1. Food reconstitution tasks.
 2. Palatability of various reconstituted and nonreconstituted foods and beverages, including temperature retention during course of the meal.
 3. Meal organization equipment, including the cleanup tasks involved.

Figure 8.6-1 displays water-heater warmup rates and maximum temperatures for each of the two process heat temperatures simulating the 14.7- and 10-psia ambient pressure cases. Water-heater capacity is shown as a function of water temperature dropoff for a maximum drawoff rate.

Tests conducted under actual 10-psia cabin pressures, producing indicated water temperatures identical to those of Figure 8.6-1, resulted in a crew consensus that preparation was practical, organization and cleanup were readily performed, food was palatable, and temperatures were maintained well beyond maximum meal duration.

Following the completion of these tests, the process heat flow to the water heater was essentially doubled due to other changes in the thermal-control process heat circuit. Subsequent testing indicated that water temperatures for the 14.7-psia (ambient) case were increased to the level of the former 10-psia (ambient) case, and temperature control was satisfactory for both cases.



- ① PROCESS HEAT TEMPERATURES WERE ADJUSTED TO SIMULATE EVAPORATION UNITS "OUT" TEMPERATURES EXPERIENCED UNDER 14.7 PSIA AMBIENT AND 10 PSIA AMBIENT. PROCESS HEAT AT EVAP UNITS, 100 LB/HR; AT FOOD WATER HEATER, 50 LB/HR

	UNIT NO. 1	UNIT NO. 2
14.7 PSIA CASE	- 180°F	186°F - TYPICAL
10 PSIA CASE	- 187°F	200°F - MINIMUM

Figure 8.6-1. Food Management Water Heater Water Temperatures

8.6.4 FINAL DEMONSTRATION TESTS. The final demonstration test conducted at a cabin ambient pressure of 10 psia recorded information pertinent to the performance of the hot and cold water circuits. Operation of the console was determined satisfactory. Typical data can be summarized as follows.

a. Hot Water Heater.

- | | |
|--|------------|
| 1. Process heat flow | 85 lb/hr |
| 2. Process heat inlet temperature | 200° F |
| 3. Coolant flow | 125 lb/hr |
| 4. Hot water temperature
(indicated) | 162° F |
| 5. Hot water temperature
(draw range) | 146-165° F |

b. Water Cooler.

- | | |
|-----------------------------------|----------|
| 1. Coolant temperature | 32° F |
| 2. Water temperature (draw range) | 36-45° F |

8.7 TEST BED PRESSURIZATION

8.7.1 VENDOR SAI TESTS. Leakage rates into the test bed must be accounted for to properly simulate the specified spacecraft-leakage rate of 33-1/3 pounds per month. Because the main chamber of the test bed was shipped to Convair in two pieces, a leakage test on the chamber was not accomplished until it was assembled at Convair. However, a leakage test was conducted at the vendor's facility on the completed air-lock chamber. On March 3, 1964 the internal pressure of the air-lock chamber was reduced to 5.3 psia. After the internal temperature appeared to stabilize, test data were taken over a period of 6 hours per the procedure described in General Dynamics Convair Report 64-26222. The calculated leakage rate over this period was 0.117 inch of water per hour, well within the allowable leakage rate of 0.554 inch of water per hour.

Initial leakage tests conducted on the installed test-bed chamber at Convair proved to be unsatisfactory. Leakage rates were approximately three times the specified maximum. However, leakage tests conducted after tank modifications, including removal of all electrical operating equipment, were satisfactory. On 8 September 1964, the test-bed chamber pressure was reduced to approximately 5 psia. The leakage test, performed in accordance with Report 62-26222, indicated a leakage rate of 0.057 inch of water per hour compared with an allowable rate of 0.083 inch of water per hour (33-1/3 pounds per month).

8.7.2 CONVAIR FUNCTIONAL CHECKOUT. A functional checkout was completed 14 November 1964. The test was completely successful, demonstrating continuity, integrity, and functional adequacy of pressure lines, components, and controls.

The following demonstrations were accomplished during checkout:

- a. Cabin and air-lock pumpdown.
- b. Cabin and air-lock safety relief.
- c. Cabin and air-lock repressurization.
- d. Cabin O₂ enrichment to 160-mm Hg partial pressure at 10-psia cabin pressure.
- e. Cabin inflow leakage compensation with O₂ makeup and cabin-to-vacuum bleed.
- f. Operation of air-lock hatches and pressure-equalizing valves.
- g. Air-lock depressurization data for setting the safe-rate valve.
- h. Emergency cabin repressurization.

The following numerical data were obtained.

- a. When the cabin and air lock are pumped down together, the relief valves open in about 10 minutes. Air-lock relief cracked at a 12.2-inch of Hg vacuum and stabilized at a 15.5-inch of Hg vacuum in 15 minutes. Cabin relief cracked at 400 mmHg_a and stabilized at 275 mmHg_a in 20 minutes.
- b. It takes 40 seconds to bring the cabin from 10-psia to atmospheric pressure, venting through one 4-inch valve.
- c. It takes 25 seconds to bring the air lock from 10-psia to atmospheric pressure, venting through the hatch pressure-equalizing valve, and 2-1/2 minutes when venting through the air-lock vacuum line vent valve.
- d. It takes 25 minutes to accomplish O₂ enrichment of the cabin atmosphere, starting from 8.5 psia and ending at 10 psia. Regulated O₂ pressure was set for 50 psig instead of 10 psig to minimize the time required for enrichment. Enrichment would take about twice as much time at the lower pressure setting.
- e. Air-lock depressurization was accomplished with five different positions of the safe-rate valve:

<u>Position</u>	<u>Depressurization Time (sec)</u>
Open	0 min 20 sec
1	1 min 24 sec
2	2 min 8 sec
3	4 min 40 sec
4	8 min 30 sec

- f. The 4-minute, 40-second run was repeated to obtain the time history of depressurization.

<u>Pressure</u> <u>(in. Hg vacuum)</u>	<u>Time</u>	<u>Equivalent</u> <u>Altitude (ft)</u>	<u>Rate of Change</u> <u>(ft/min)</u>
0	0	0	
2	0 min 35 sec	1905	3260
4	1 min 30 sec	3918	2200
6	2 min 28 sec	6068	2220
8	3 min 35 sec	8362	2050
9.6	4 min 40 sec	10,329	1820

The safe-rate valve was lockwired to the 4-minute, 40-second position since it will permit insertion of a four-man crew in approximately 20 minutes, and the rate will be comfortable to most personnel. An individual experiencing discomfort can reduce the rate or completely stop depressurization by means of the modulating and shutoff valve located in the air lock.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

The program objectives were effectively achieved, in that a four-man, integrated, regenerable life-support system has been developed and operationally demonstrated. The program has provided much needed insight to the practical problems of hardware development, and the conceptual aspects of the various subsystems have been evaluated and in most cases verified as feasible. Experience gained during this program will provide guidance for continued progress in the development of life-support systems for missions of extended duration.

The interdisciplinary skills and hardware testing utilized in the present program must be significantly expanded prior to the initiation of long-duration manned tests. Increased system efficiency could be obtained by utilizing processes that could recover and make use of the carbon produced during CO₂ reduction and now stored and of the excess hydrogen generated by the electrolysis unit and now discharged overboard. Conceptually, there are processes that appear promising for this use.

The following observations are based upon a review of system tests conducted under this program.

9.1 LEAKAGE

Nearly all the developed equipment required extreme care in fabrication and assembly to avoid unacceptable leakage of process fluids. Very little external leakage could be tolerated from the reduction unit and catalytic burner, because of the possibility of introducing toxic gases into the test bed atmosphere.

The concentration unit was critical with respect to leakage from the standpoint of introducing air into the desorbing CO₂, thus reducing purity to an unacceptable level. This unit was also critical with respect to leaking moist air into the adsorbing zeolite system.

The waste management system was required to have low gas leakage to minimize the amount of cabin air that might be vented overboard and thus require added makeup from atmospheric stores. The cabin air-water separator seemed to leak air into the water cavity in a random fashion. This air must eventually be eliminated from the water management system; it could possibly become a problem if natural elimination of the air through the process air circuit of the air evaporation unit is found to be either inadequate to eliminate system problems or deleterious to subsystem performance.

The problem of minimizing gas leakage is greatly increased over that presented in standard engineering applications because of the very low process flow rates required of the equipment. Although it is recognized that essentially leak-free systems may be achieved, the importance of adequate consideration of this requirement and resultant system design aimed at achieving minimum leakage must be strongly emphasized in the initiation of future equipment design.

All liquid lines were subject to leakage at valves and line connections. For the fluids and temperatures used in this system, leakage is probable unless extreme care is taken with line connections and unless valves are selected with due regard to material characteristics when exposed to the liquids.

The electrolysis unit presented leakage difficulties in both the gas and liquid circuits. It is expected that a continuing leakage problem will be experienced with this unit because of the large number of connections required and the inherent characteristics in unit design.

9.2 WATER TREATMENT

Although testing was not sufficiently extensive to evaluate the proposed water treatment concepts fully, the experience gained does indicate that these concepts should be re-examined.

It is possible that the requirement for essentially bacteria-free water from the processing units may be made less stringent by considering thermal post-treatment for potable water and chemical post-treatment for the wash water supply. This treatment may eliminate the need for holding tanks and the accompanying requirement for making bacterial checks prior to introducing processed water into the potable system. The methods and equipment for the present chemical pretreatment of waste waters is questionable in terms of inherent accuracy, particularly when used in an engineering development program rather than as part of steady-state operational system. The problem arises from the fact that the liquid circuits must be free of gases to permit accurate metering of chemicals with the injector system.

9.3 INSTRUMENTATION AND CONTROLS

Instrumentation requirements must be carefully evaluated and equipment penetration points minimized to avoid the leakage problems.

System control requirements may be restrictive because of inherent subsystem design characteristics. An example of this is provided by the requirement for a relatively complex pressure-control system and operating procedure for the water electrolysis unit. This requirement is associated with the gas-liquid interfaces at the ion-exchange membranes and the porous separator plates. Pressure differential

across the membrane is critical (because of the limited mechanical strength of the membrane), and the porous separator plate will allow liquid to back-flow through the separator unless proper differential pressure is maintained across the separator. The requirement for accurate pressure control is a result of integration of the electrolysis unit into the overall system and is a consequence of using a porous plate liquid-gas separator.

9.4 GAS ANALYSIS

On-line direct reading and recording instrumentation for much of the process gas analysis is recommended, since the requirement for trace-contaminant analysis frequently coincides with that for process gas analysis.

Problems encountered in evaluating standard samples indicated interaction of compounds either during freeze-out or thawing and volatilization of samples for analysis. Techniques should be developed to identify primary contaminants more effectively.

Improved techniques with high sensitivity will be required to identify and monitor trace contaminants within the test bed. Multiple techniques are desirable to substantiate the identification of contaminants and to ensure reliable information regarding safe contaminant level during manned tests.

9.5 SUBSYSTEM AND COMPONENT FUNCTIONS

9.5.1 ELECTROLYSIS UNIT. The fundamental problem experienced during the test program was degradation of the cell membrane assemblies. Degradation was believed to be directly attributable to operation with a design cell temperature of approximately 150°F. A temperature control was installed to limit cell temperature to about 90°F, and no further degradation was observed. This is not significant, however, as very little operational time was accumulated after incorporation of the lower cell temperature. If additional testing still indicates unacceptable cell degradation, a new or radically modified cell configuration will be required.

9.5.2 LIQUID-GAS SEPARATORS. Both dynamic and static liquid-gas separators were employed. The static separators utilized a porous plate as a liquid-gas interface and depended on capillary forces in the pores to prevent gases from passing through the plates. The dynamic separators utilized centrifugal forces from a rotating assembly, driven either by a direct-connected air turbine or an electric motor.

As originally designed, all the separators failed to function properly, although component modification permitted satisfactory subsystem operation. A development program is needed to produce operational separators.

9.5.3 ZERO-G PROCESS VERIFICATION. Although all equipment was conceptually designed to be compatible with a zero-g environment, it was not possible to verify these concepts. As the system matures, it is recommended that a systematic parallel program be developed to test and verify selected processes for gravitational dependency. This would eventually evolve into a system flight test program with candidate subsystems having been screened by the initial phases of such a program.

9.5.4 ENERGY CONVERSION. It has been demonstrated that thermal energy can be effectively utilized in critical life-support system processes through the application of waste heat supplied through a liquid transport circuit. This is significant because electrical energy requirements may be reduced or may be allocated to more restrictive applications.

9.5.5 GROUND SUPPORT EQUIPMENT. The ground support equipment providing process heat fluid to the life-support equipment was initially deficient in operation. Problems of inadequate fluid temperature control and of fluid contaminant generation within the unit itself due to materials incompatibility were encountered. Modification and installation of filters prevented contamination of the life-support equipment being supplied. Filtering systems should always be provided to prevent contaminant transport and to allow replacement of filters without system shutdown.

9.5.6 GROWTH OF MICRO-ORGANISM. There has been no opportunity to investigate the potential problem of micro-organism growths in filters and other elements of the LSS and test bed. The research program at NASA/LRC should include a comprehensive study of the microbiological controls appropriate to long duration manned testing.

APPENDIX A

CALIBRATION DATA

The calibration and analytical information contained herein is provided for evaluating test results and facilitating operation of the LSS. These data describe the performance characteristics of the life support system in its delivered configuration as employed at the final demonstration tests at Convair in July 1965.

Certain data pertaining to earlier configurations are also included.

Figure No.

THERMAL CONTROL

Air Circuit

A-1	Psychrometric Chart - 10 psia
A-2	Orifice Calibration
A-3	Blower Performance Curve - System A
A-4	Blower Performance Curve - System B
A-5	Blower Performance Curve - Suit Loop Circuit

Liquid Coolant Circuit

A-6	Physical Properties, FC-75
A-7	Dynamic Viscosity, FC-75
A-8	Orifice Calibration, FC-75
A-9	Physical Properties, 40 Percent Aqueous Propylene Glycol
A-10	Dynamic Viscosity, 40 Percent Aqueous Propylene Glycol
A-11	Orifice Calibration, 40 Percent Aqueous Propylene Glycol

Coolant Fluid Heater

A-12	Dial Thermometer Calibration
A-13	Heating Capacity

Fluid Cooling and Pumping Unit

A-14	Dial Thermometer Calibration
------	------------------------------

Figure No.

THERMAL CONTROL, Contd

Fluid Cooling and Pumping Unit, Contd

- | | |
|------|--|
| A-15 | Pressure Gauge Calibration |
| A-16 | Pumping Characteristics, (FC-75) |
| A-17 | Flow Meter Calibration, FC-75 vs. Propylene Glycol |

Process Heat Circuit

- | | |
|------|-----------------------------|
| A-18 | Physical Properties, DC-331 |
| A-19 | Dynamic Viscosity, DC-331 |
| A-20 | Orifice Calibration |

Fluid Heating and Pumping Unit

- | | |
|------|------------------------------|
| A-21 | Dial Thermometer Calibration |
| | Pressure Gauge Calibration |
| A-22 | Pumping Characteristics |

ATMOSPHERIC CONTROL

CO₂ Concentration Unit

- | | |
|------|---|
| A-23 | Orifice Calibration - Inlet Orifice |
| A-24 | Orifice Calibration - Installed Orifice |
| A-25 | Blower Performance Curve |
| A-26 | Pump Performance Curves |
| A-27 | Hygrometer Pressure Correction Curve |
| A-28 | Flowmeter Calibration |

CO₂ Reduction Unit

- | | |
|------|---------------------------------|
| A-29 | Feed Flow Meter Settings |
| A-30 | Recycle Flowmeter Calibration |
| A-31 | Purge-Gas Flowmeter Calibration |

Figure No.

ATMOSPHERIC CONTROL, Contd

Water Electrolysis Unit

- A-32 Specific Gravity of Aqueous Sulphuric Acid Solutions
 Module B Nitrogen Pressure Drop Characteristics
 Module B Water Pressure Drop Characteristics
 Module B Coolant Pressure Drop Characteristics
 Unit Coolant Pressure Drop Characteristics

CONTAMINANT CONTROL

Catalytic Burner

- A-33 Blower Performance Curve
A-34 Filter Pressure Drop Characteristics
A-35 Orifice Calibration
 Heating Characteristics - Unit No. 1
 Heating Characteristics - Unit No. 2
 Warm-up Heating Requirements
A-36 Pyrometer Calibration

WATER MANAGEMENT

Water Recovery Units

- A-37 Blower Performance Curve
A-38 Flow Calibration - Heat Exchanger

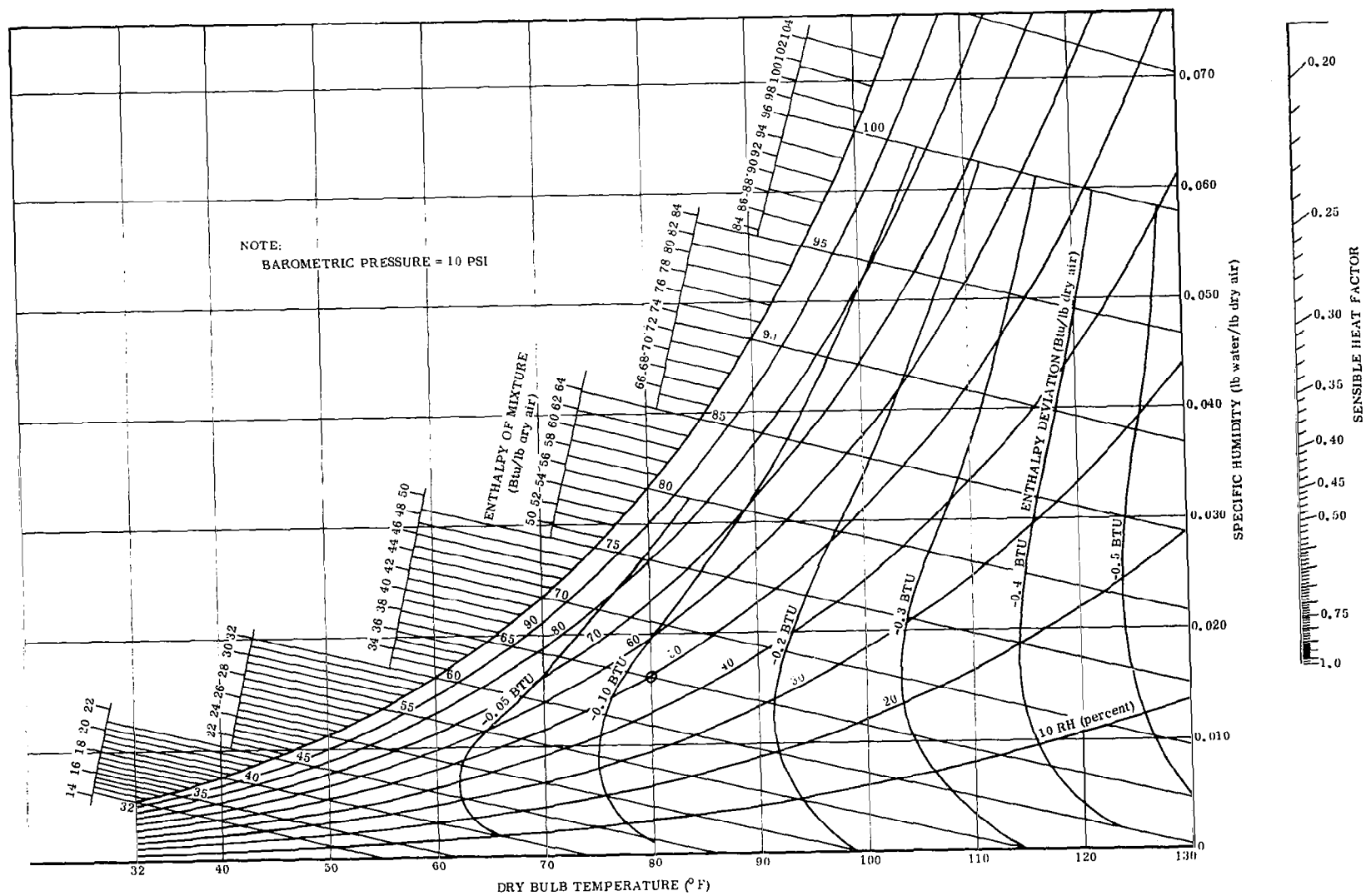


Figure A-1. Psychrometric Chart

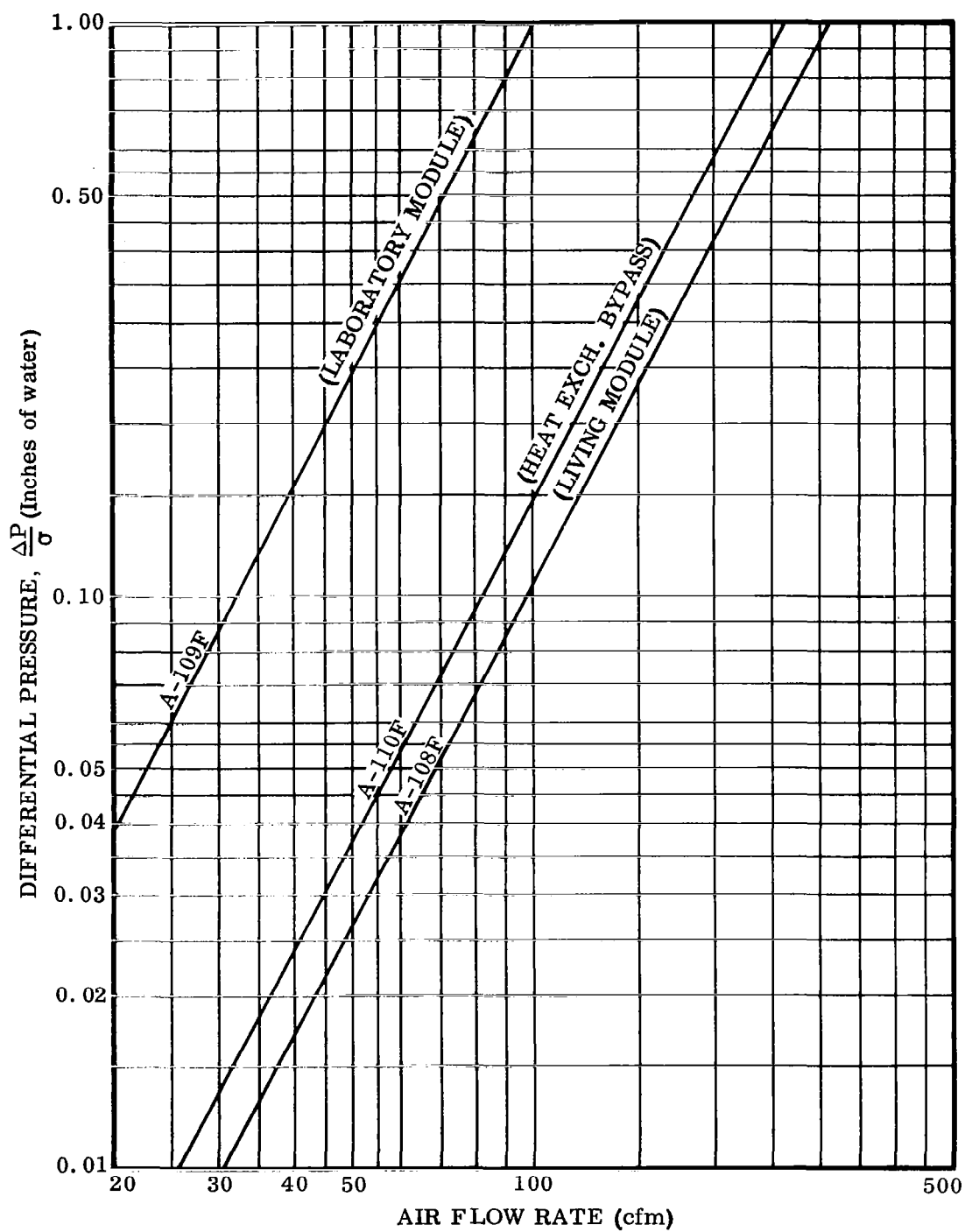


Figure A-2. Orifice Calibration, Thermal Control Air Circuit

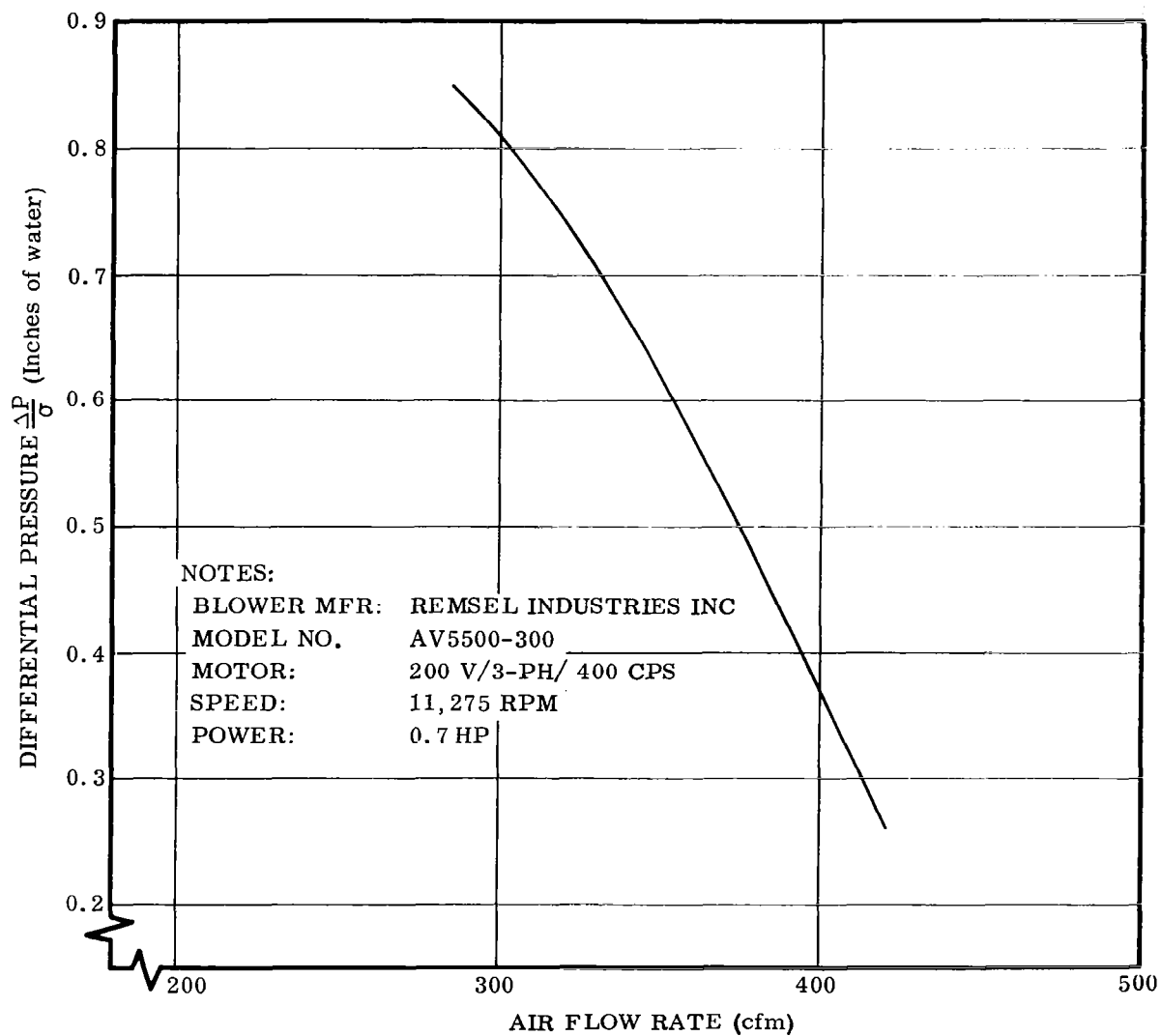


Figure A-3. Blower Performance, Main Cabin Air Blower, System "A"

NOT AVAILABLE

Figure A-4. Blower Performance, Main Cabin Air Blower, System "B"

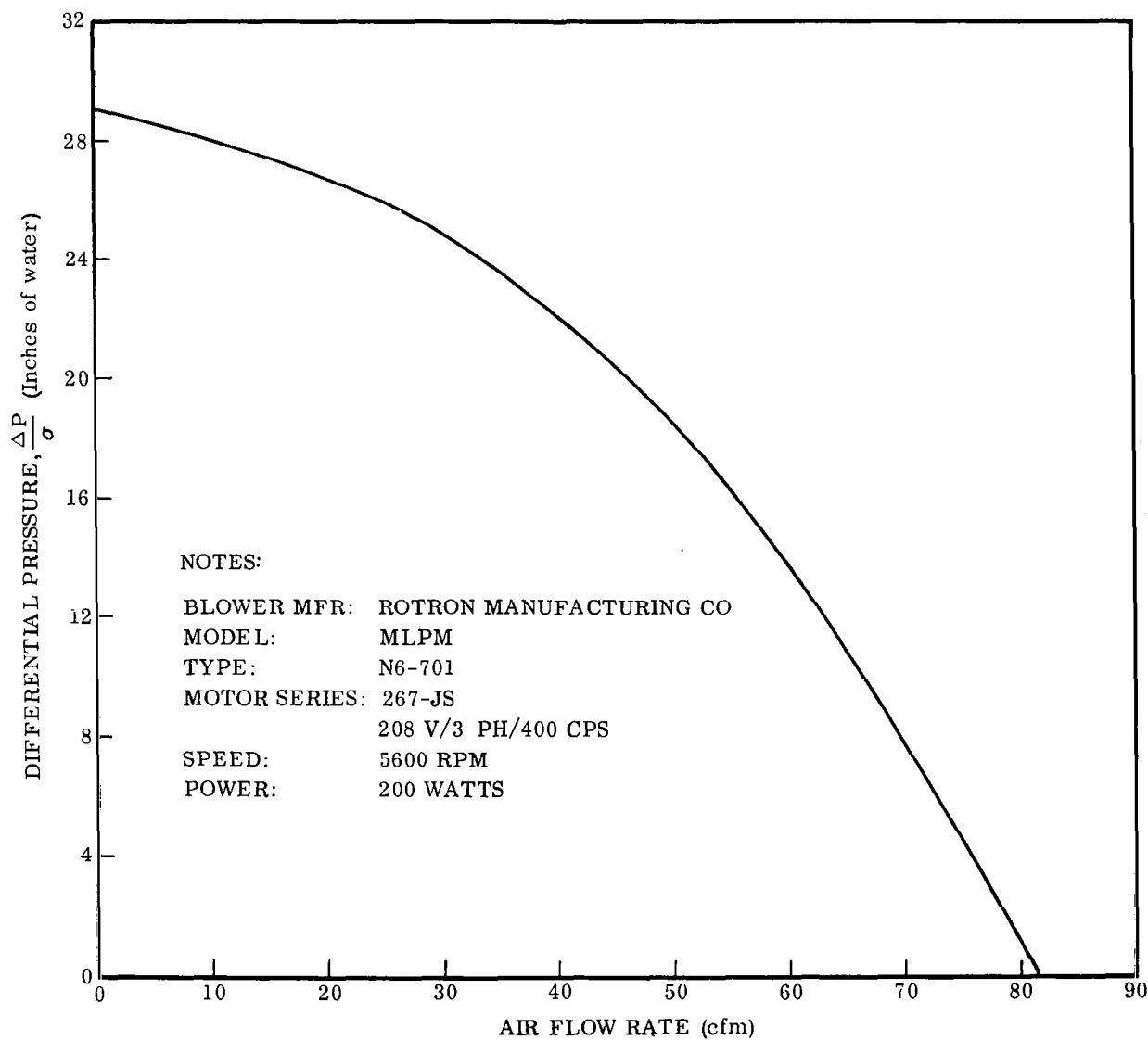


Figure A-5. Blower Performance, Suit Loop Circuit

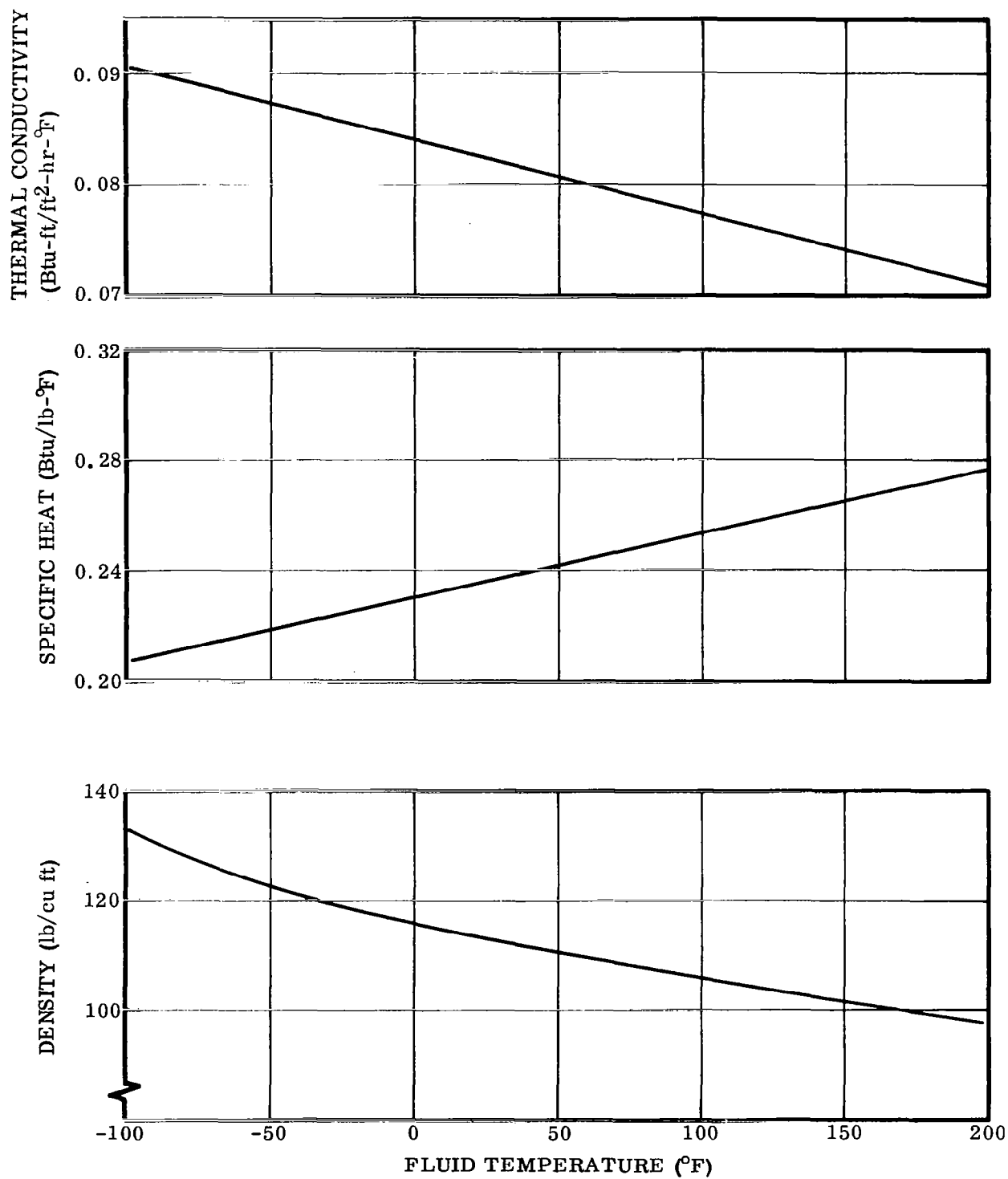


Figure A-6. Physical Characteristics, FC-75

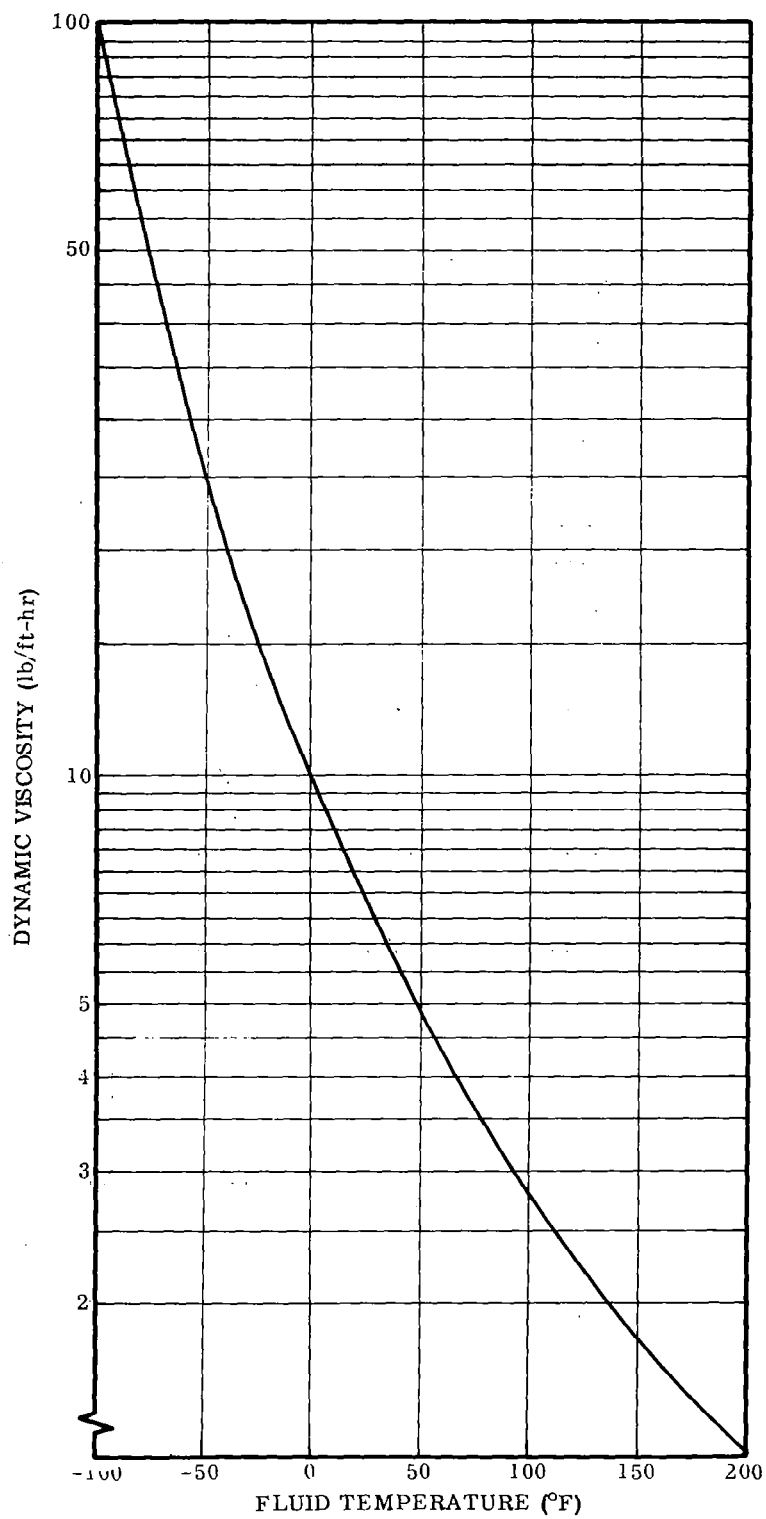


Figure A-7. Dynamic Viscosity, FC-75

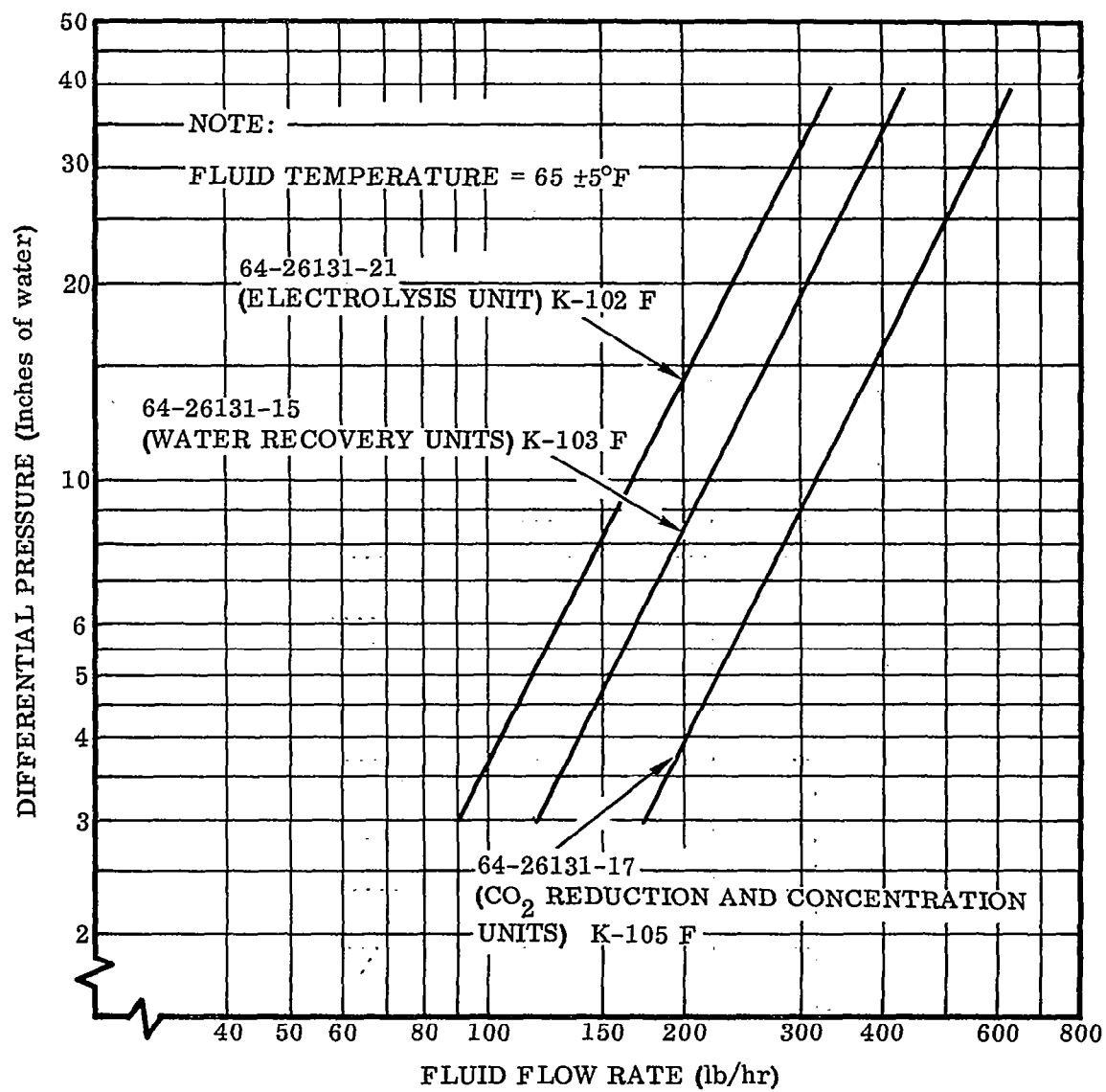


Figure A-8. Orifice Calibration, Liquid Coolant (FC-75) Circuit

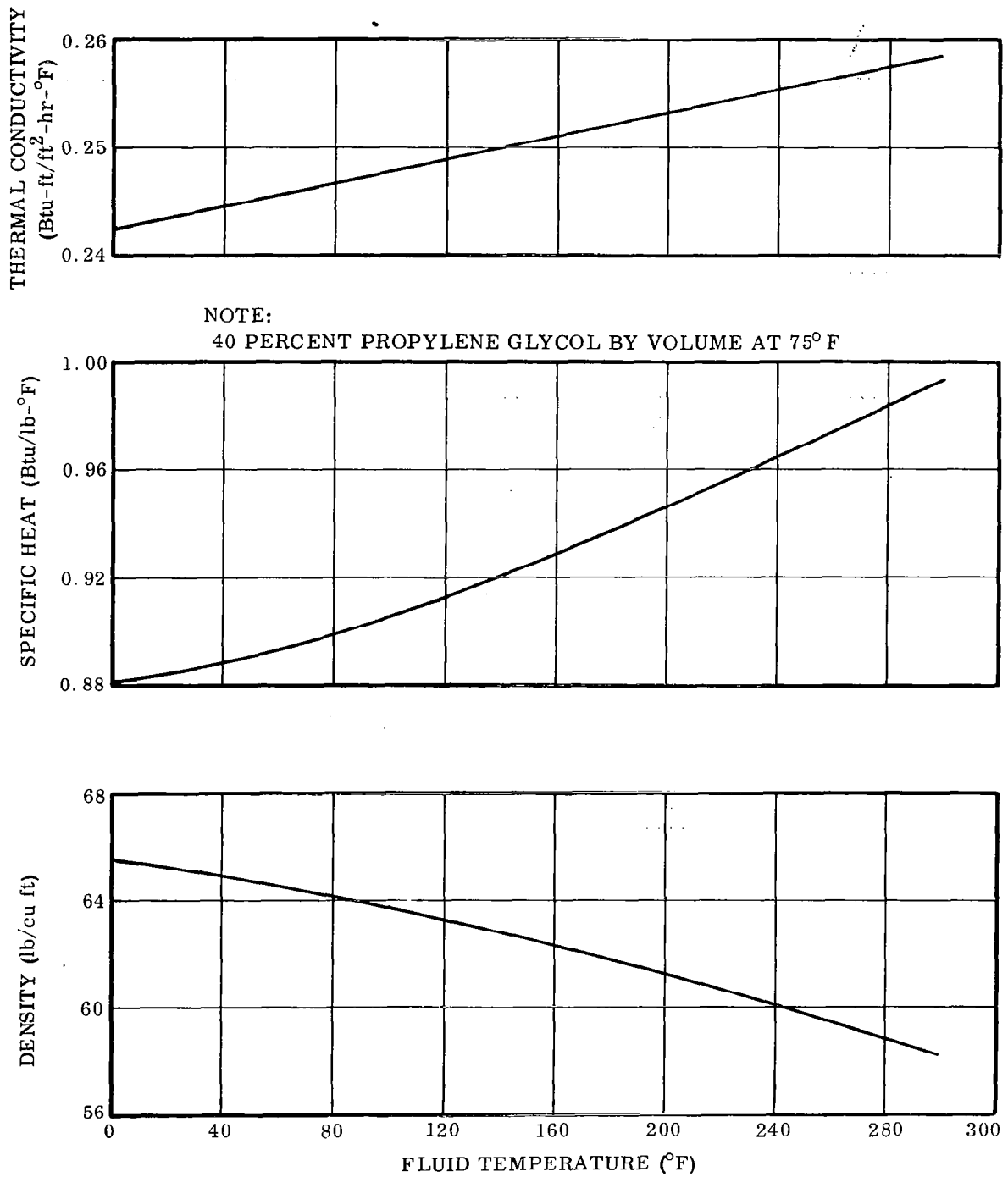


Figure A-9. Physical Characteristics, Aqueous Propylene Glycol

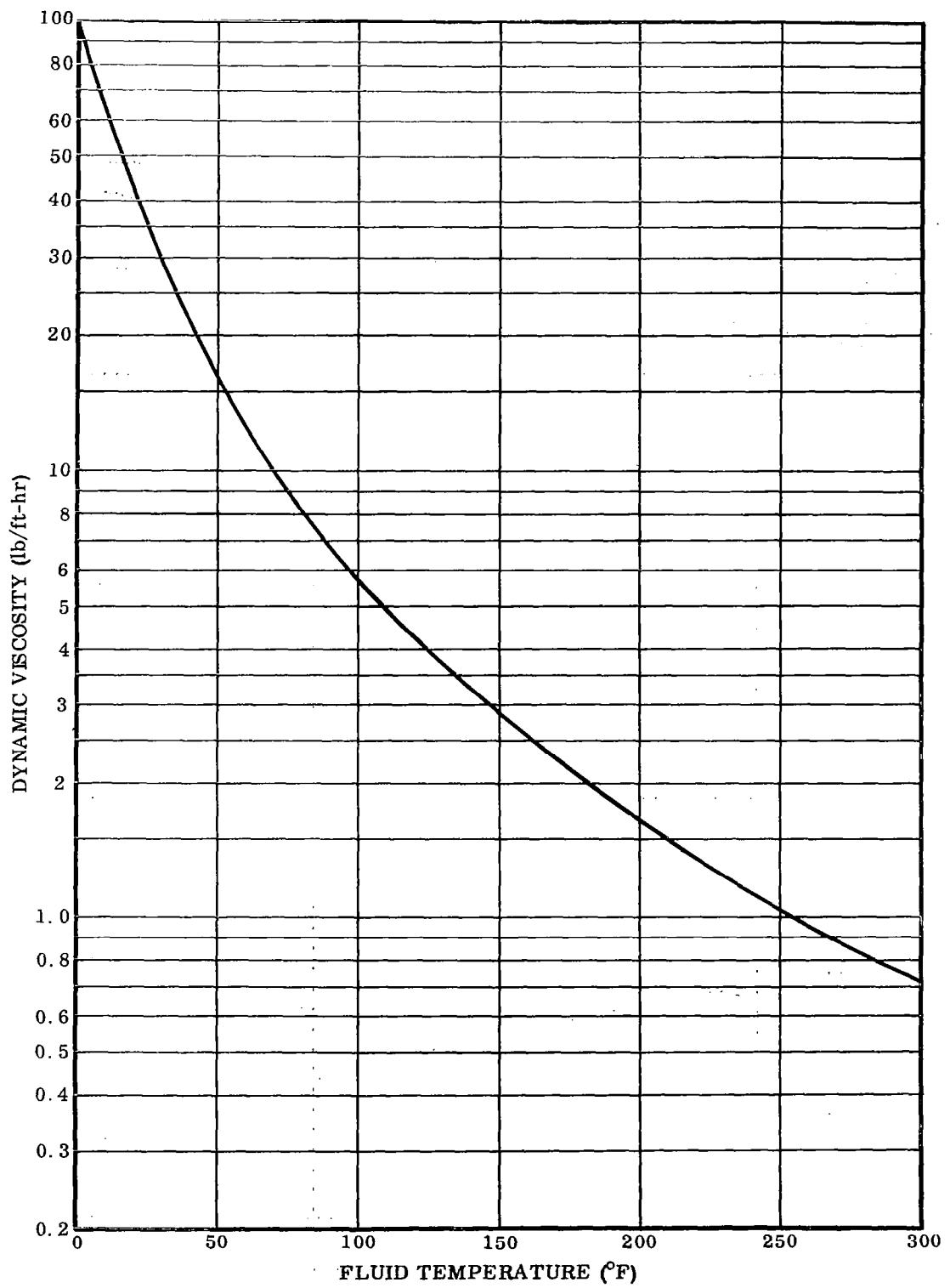


Figure A-10. Dynamic Viscosity, Aqueous Propylene Glycol

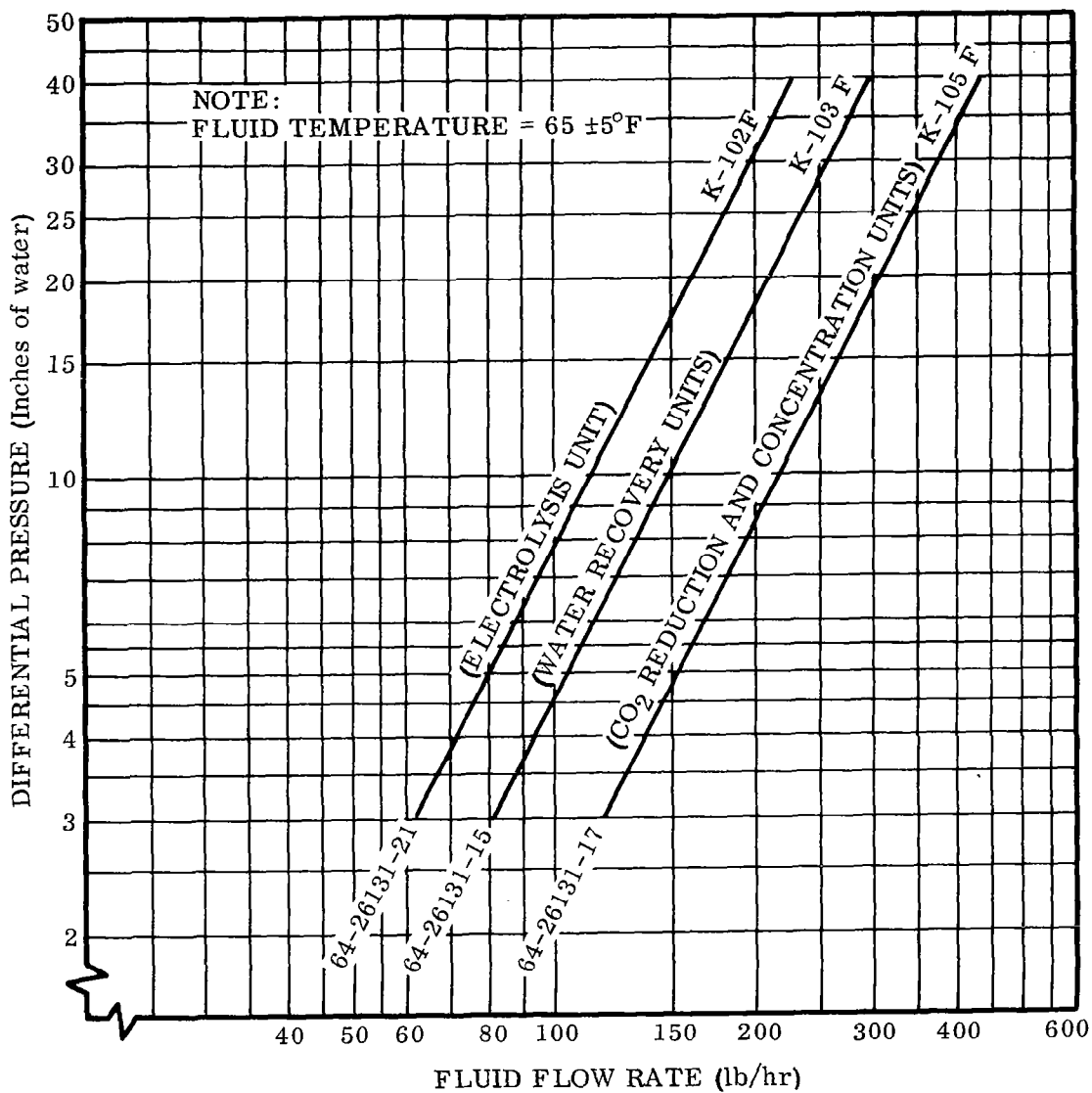


Figure A-11. Orifice Calibration (Aqueous Propylene Glycol) Circuit

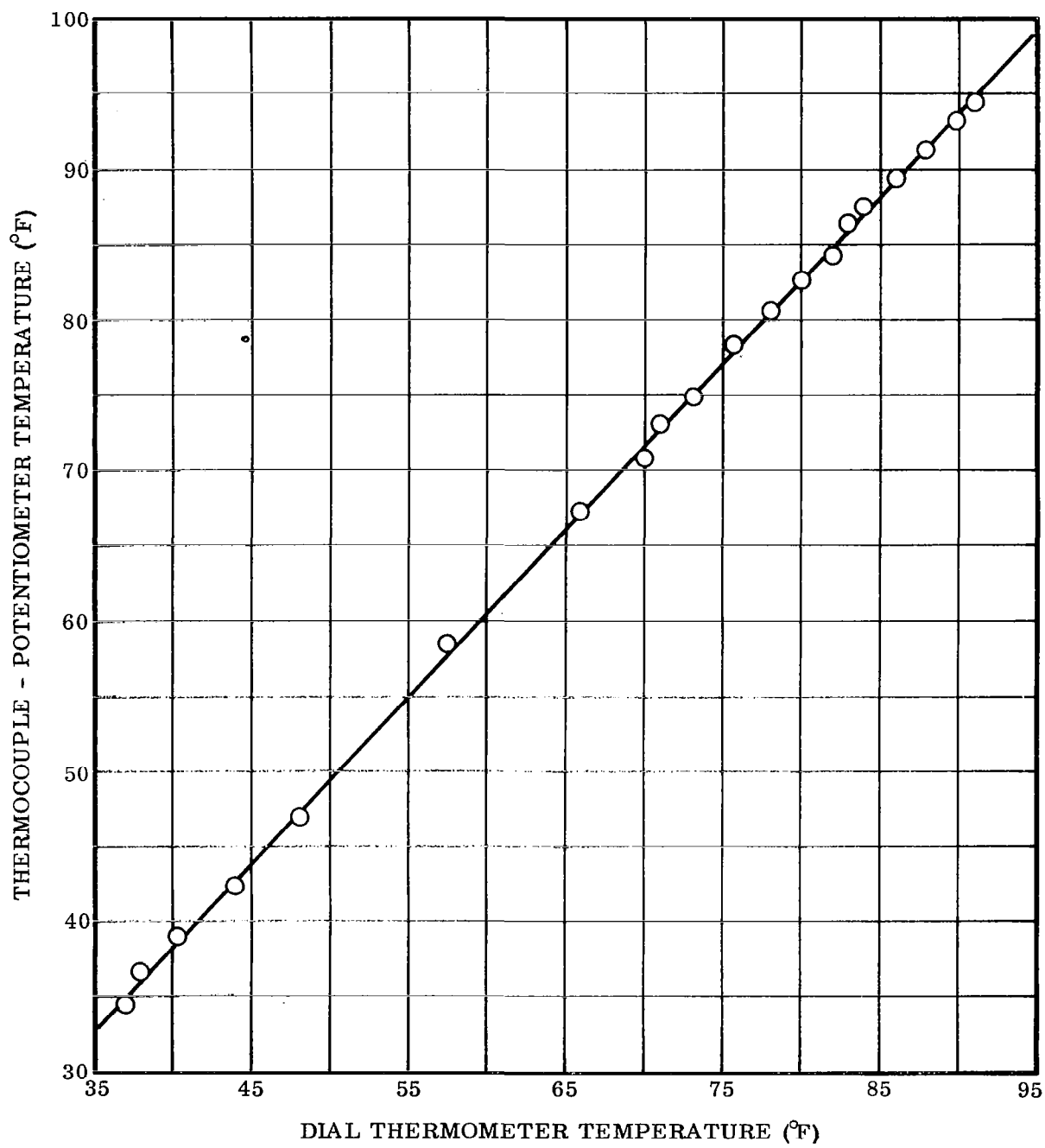


Figure A-12. Dial Thermometer Calibration, Coolant Fluid Heater

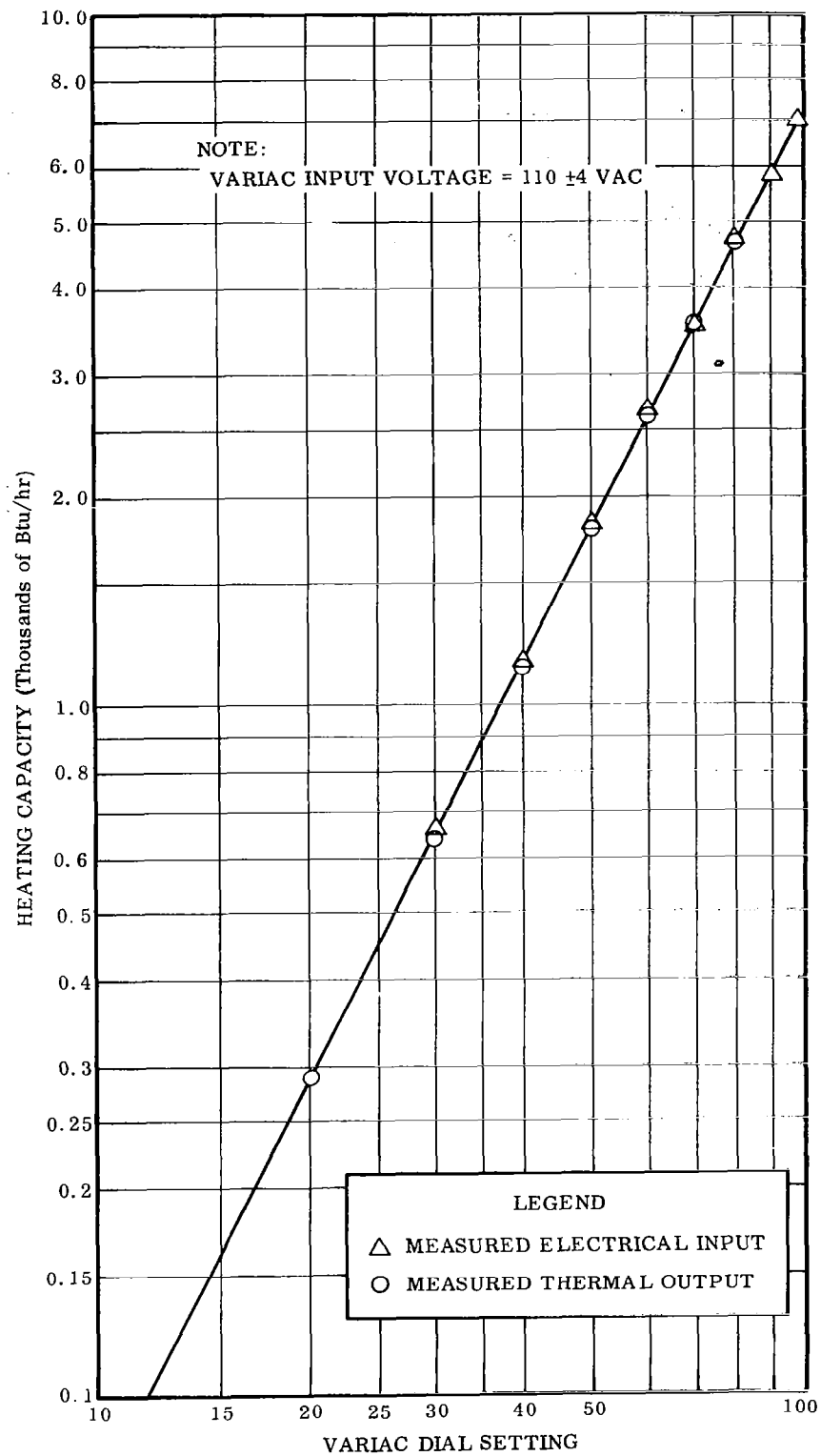
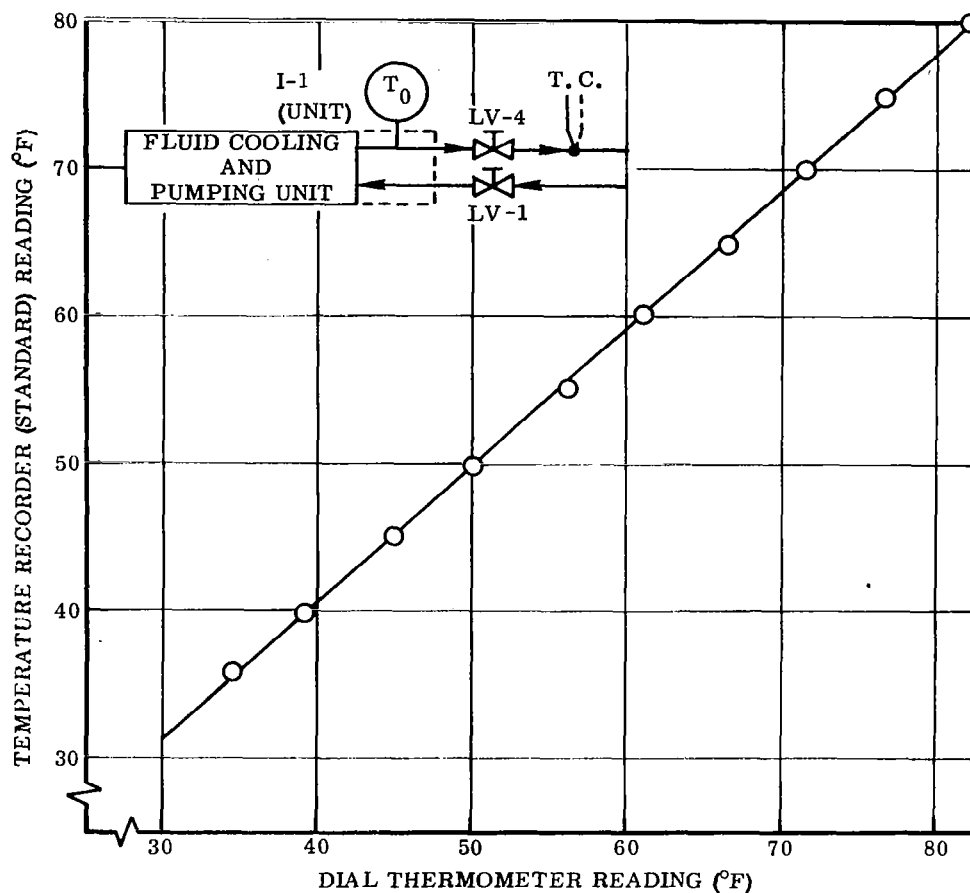


Figure A-13. Heating Capacity, Coolant Fluid Heater (Power System Simulator)



NOTES

FLUID (FC-75) FLOW RATE = 2500 lb/hr

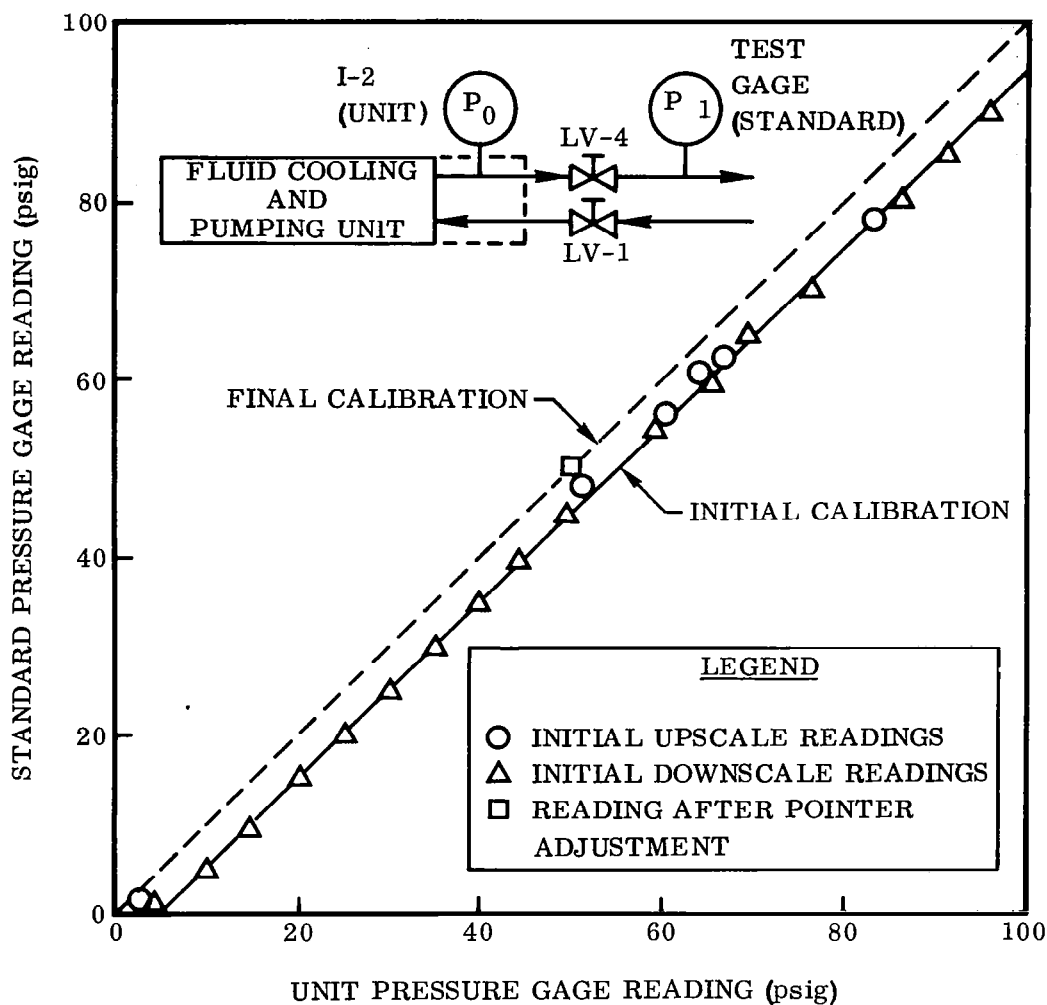
UNIT INSTRUMENT

INSTR: DIAL THERMOMETER
 MFR: MARSHALLTOWN MFG CO
 MODEL: TYPE B, 21/2-INCH
 RANGE: -40 TO +120 °F
 SERIAL NO. NONE
 LOCATION:
 FLUID DISCHARGE TEMPERATURE
 GAGE ON FLUID COOLING AND
 PUMPING UNIT

STANDARD INSTRUMENT

INSTR: TEMPERATURE RECORDER WITH T.C.
 MFR: MINNEAPOLIS HONEYWELL REG CO
 MODEL: 153X72-P12-II-III-26
 RANGE: -30 TO 230 °F
 SERIAL NO. 932515
 CALIBRATION:
 DATE: 1 SEPTEMBER 1964
 LABORATORY: MINNEAPOLIS HONEYWELL

Figure A-14. Dial Thermometer Calibration, Fluid Cooling and Pumping Unit



NOTES:

FLUID FLOW RATE = 0

UNIT INSTRUMENT

INSTR: PRESSURE GAGE
MFR: MARSHALLTOWN MFG CO
MODEL: TYPE B, 2 1/2-INCH
RANGE: 0 TO 100 PSIG
SERIAL NO. NONE
LOCATION:

FLUID DISCHARGE PRESSURE GAGE
(I-2) ON FLUID COOLING AND
PUMPING UNIT

STANDARD INSTRUMENT

INSTR: PRESSURE GAGE
MFR: ASHCROFT
MODEL: AMC-4296, 4 1/2-INCH
RANGE: 0 TO 600 PSIG
SERIAL NO. T-27 (INVENTORY NO.)
CALIBRATION:

DATE: 25 AUGUST 1964
LABORATORY: WILEY
ACCURACY: $\pm 0.25\%$ FULL SCALE

Figure A-15. Pressure Gage Calibration, Fluid Cooling and Pumping Unit

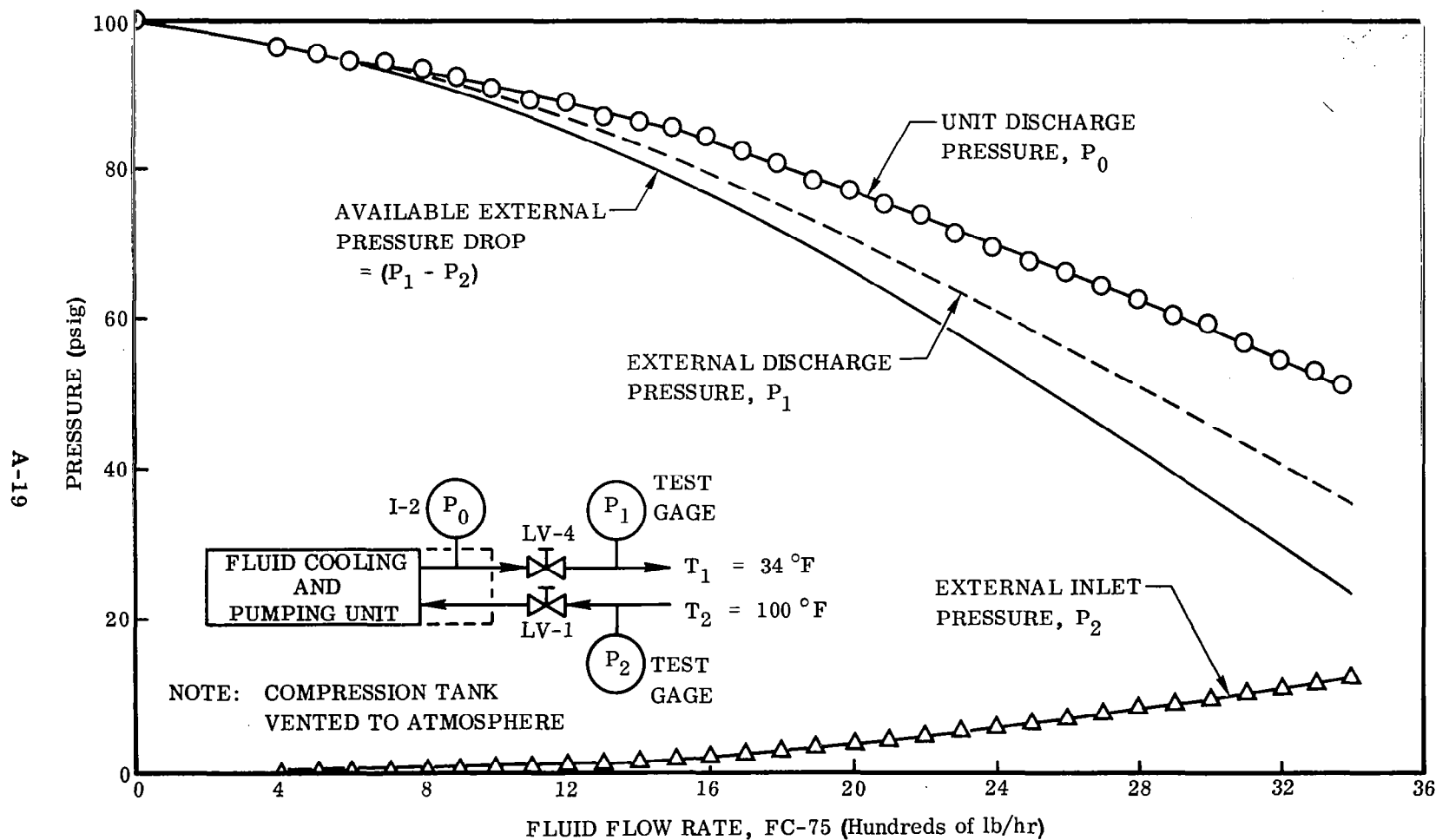


Figure A-16. Pumping Characteristics, Fluid Cooling and Pumping Unit

A-20

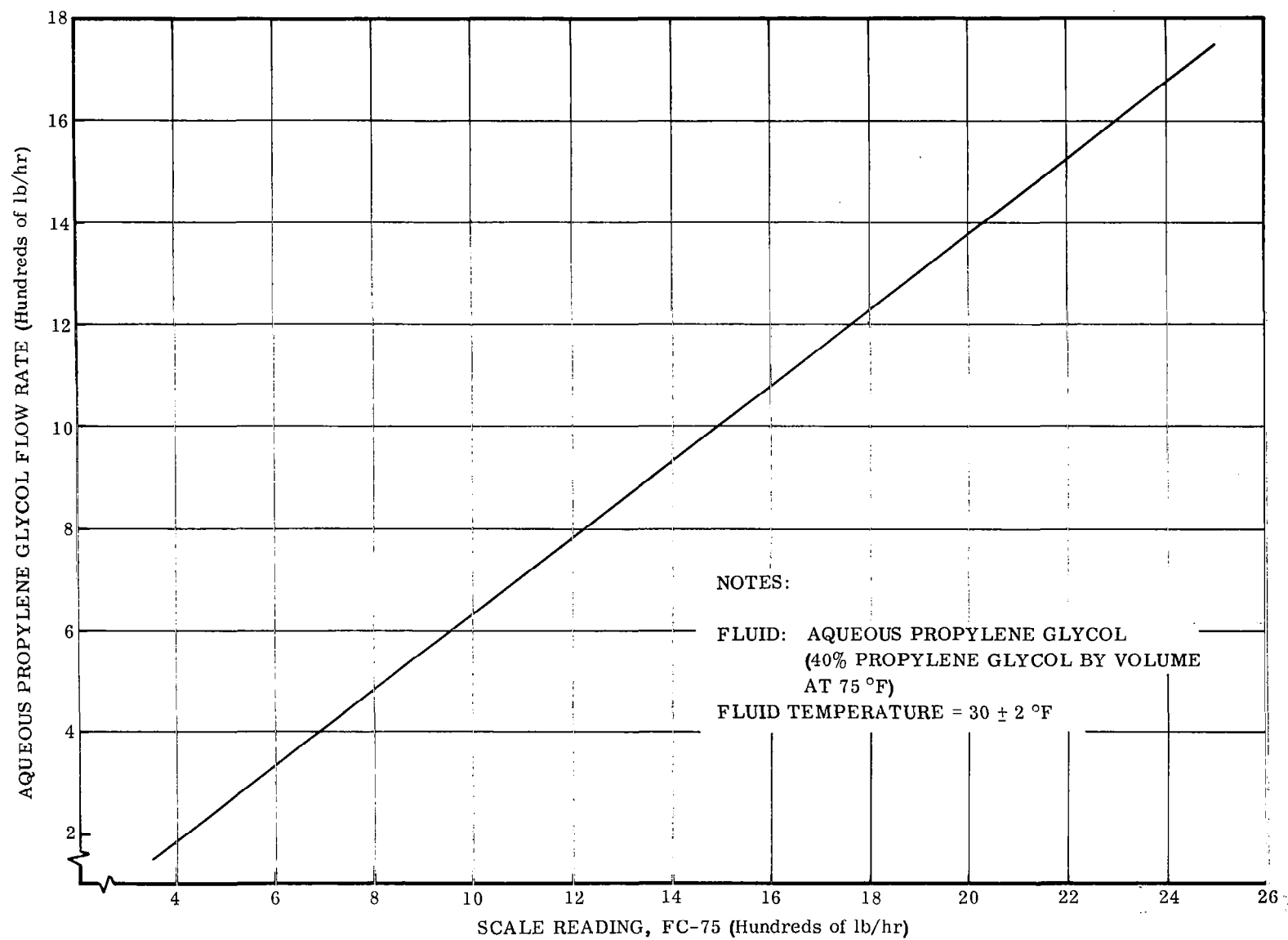


Figure A-17. Flowmeter Calibration, Fluid Cooling and Pumping Unit

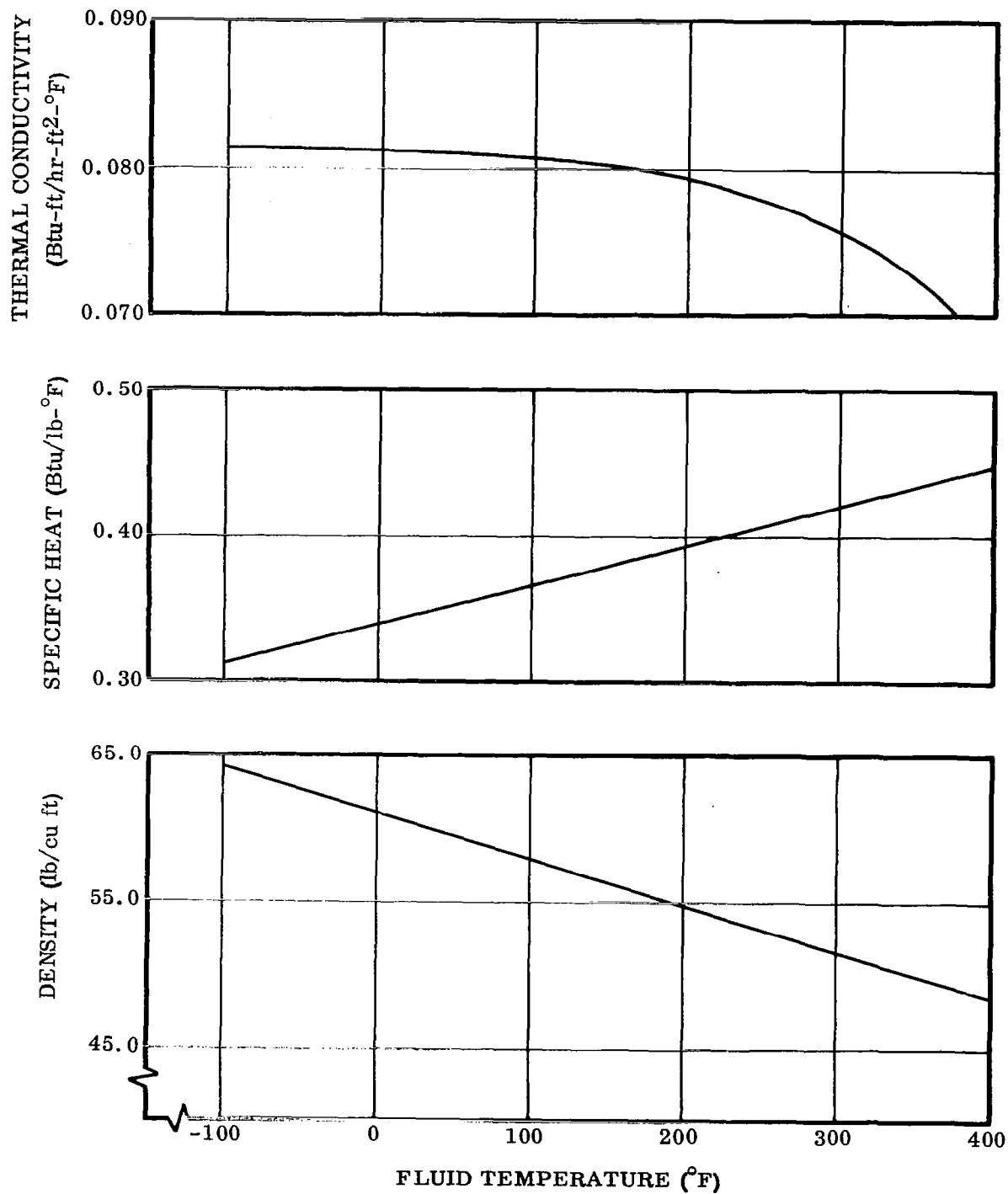


Figure A-18. Physical Characteristics, Dow Corning 331

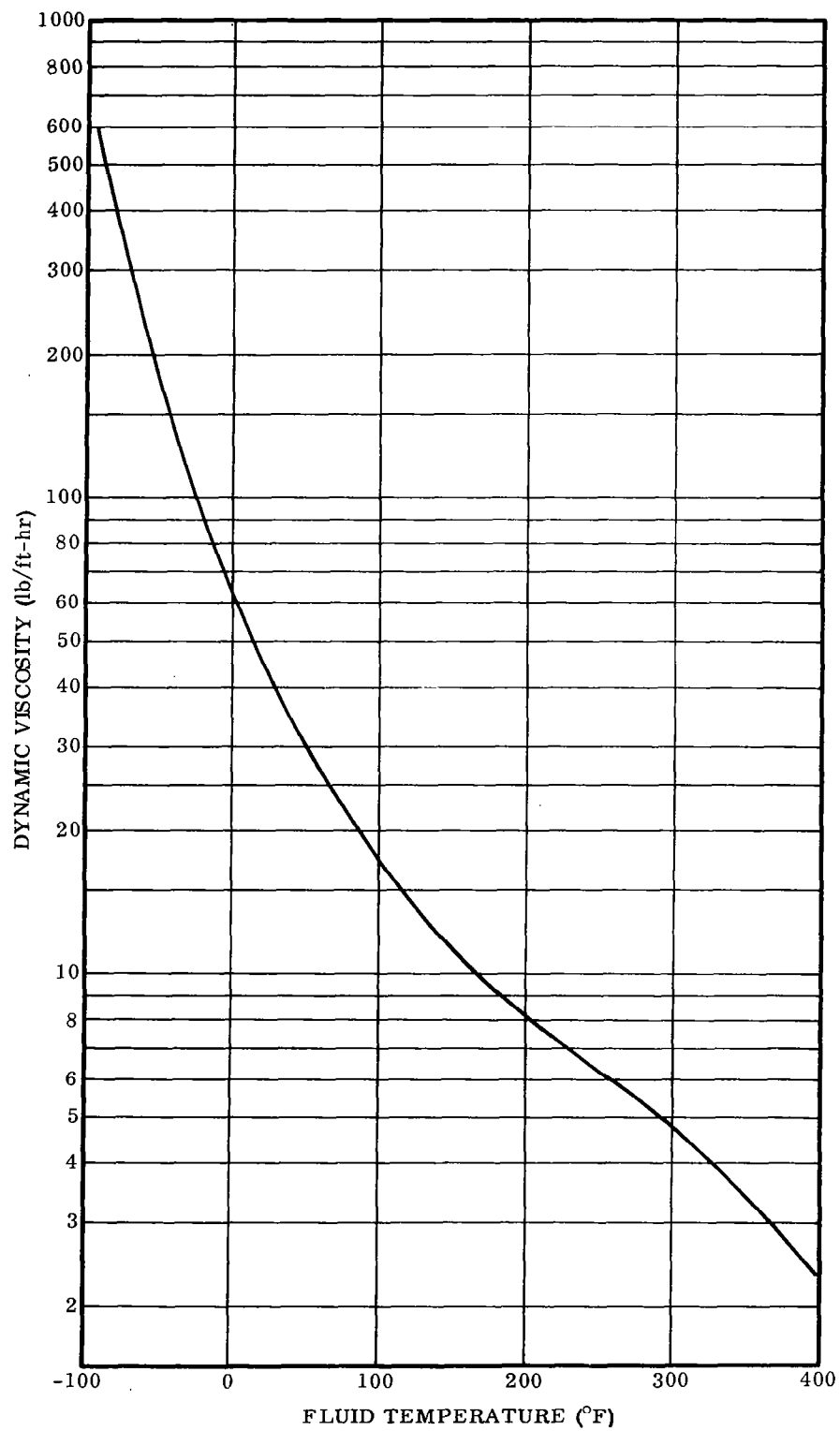


Figure A-19. Dynamic Viscosity, Dow Corning 331

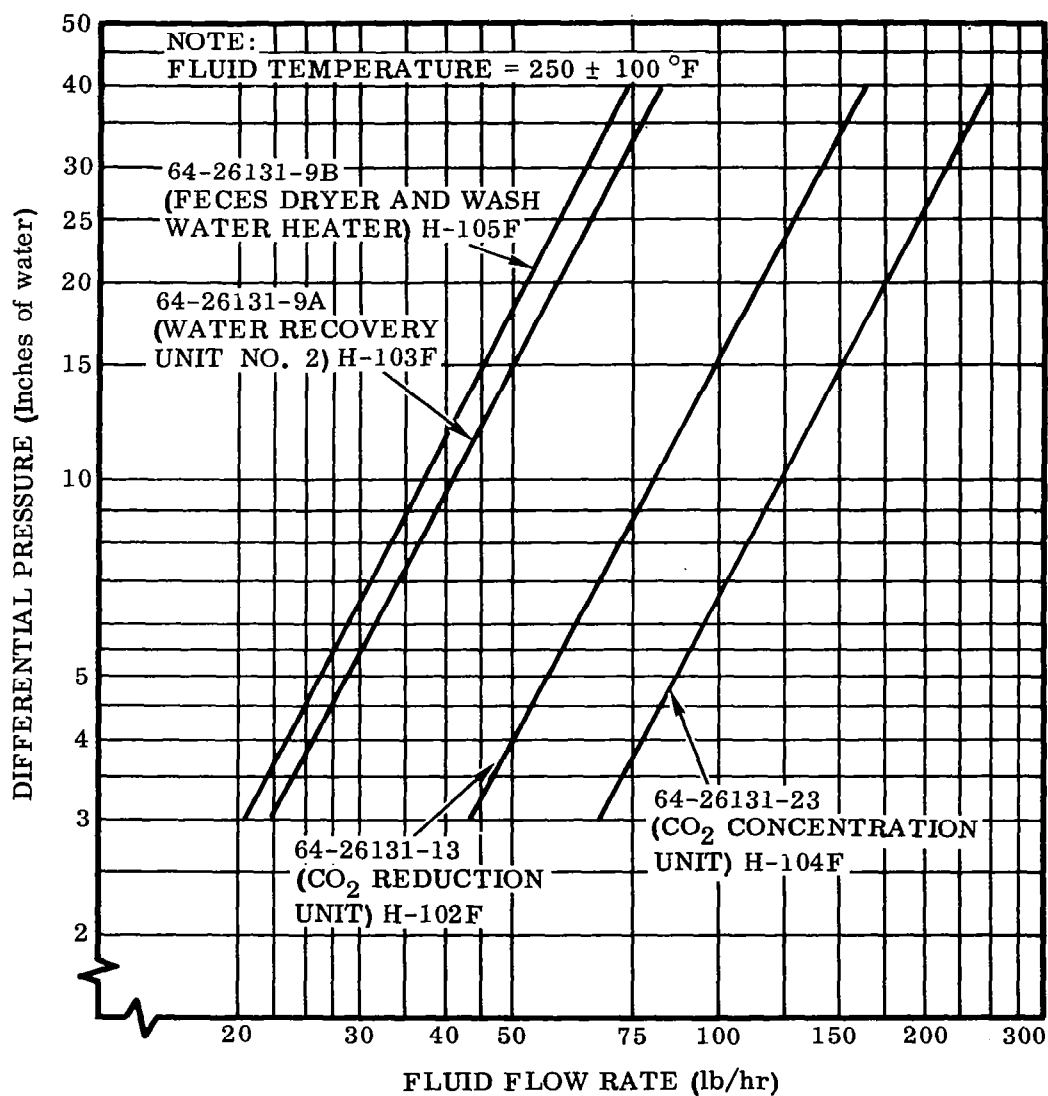
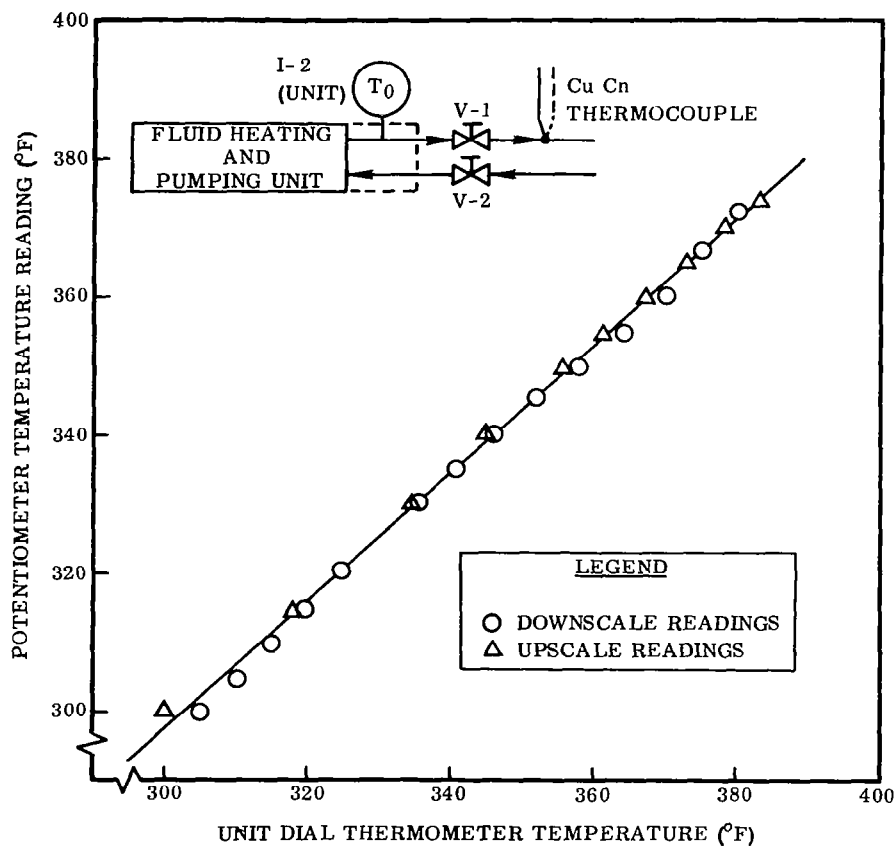


Figure A-20. Orifice Calibration, Process Heat (DC-331) Circuit



NOTES:

UNIT INSTRUMENT

INSTR: BI-METAL DIAL THERMOMETER
 MFR: MARSHALLTOWN MFG CO
 MODEL: TYPE B, 2 1/2-INCH
 RANGE: 50 - 500 °F
 SERIAL NO. NONE
 LOCATION:
 FLUID DISCHARGE TEMPERATURE
 GAGE (I-2) ON FLUID HEATING
 AND PUMPING UNIT

STANDARD INSTRUMENT

INSTR: POTENTIOMETER WITH THERMO-
 COUPLE
 MFR: LEEDS AND NORTHRUP
 MODEL: PORTABLE
 RANGE: -100 TO +400 °F
 SERIAL NO. 1512370
 CALIBRATION:
 DATE: 21 JULY 1964
 LABORATORY: NATIONAL
 ACCURACY: ± 1.5 °F

Figure A-21. Dial Thermometer Calibration, Fluid Heating and Pumping Unit

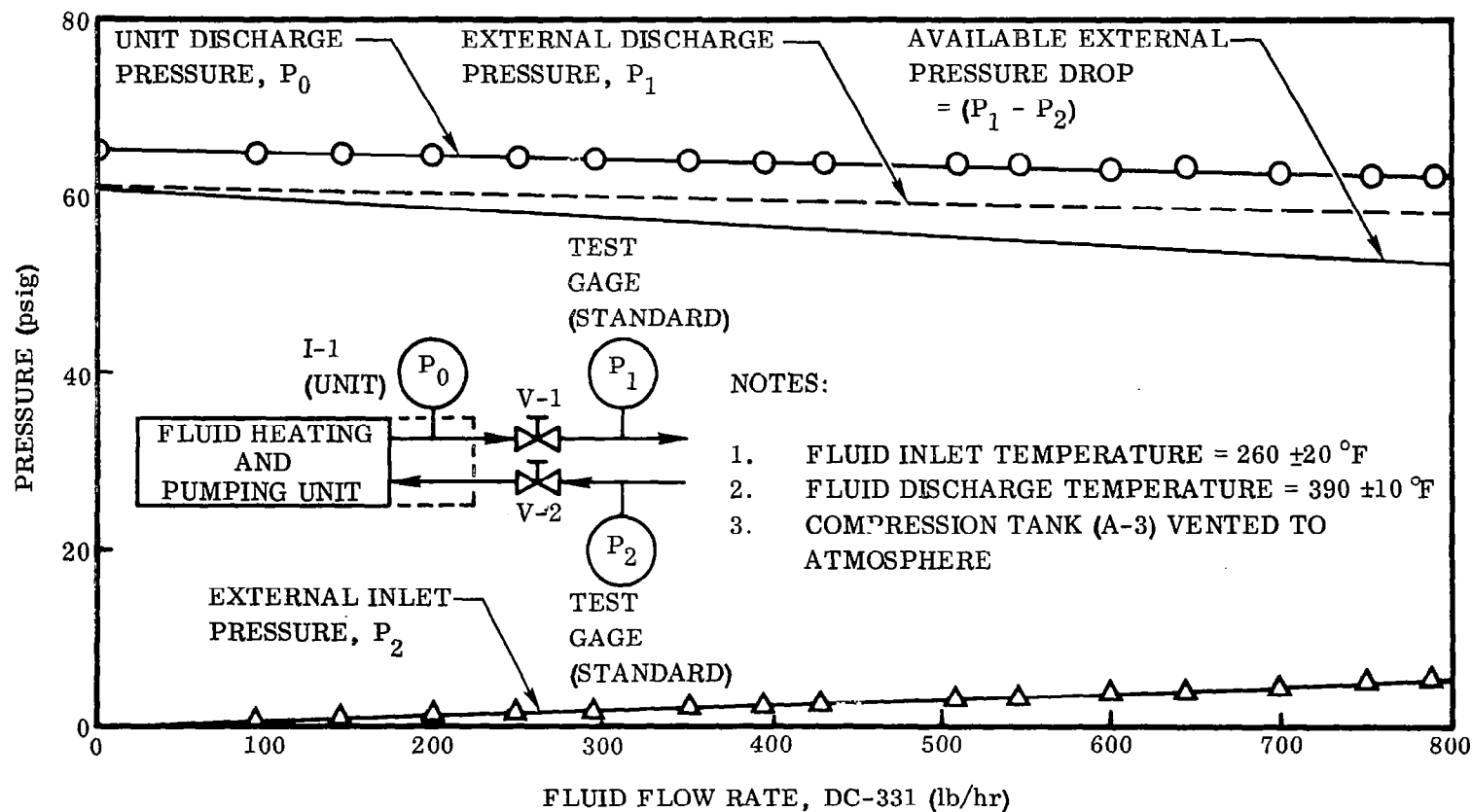


Figure A-22. Pumping Characteristics, Fluid Heating and Pumping Unit

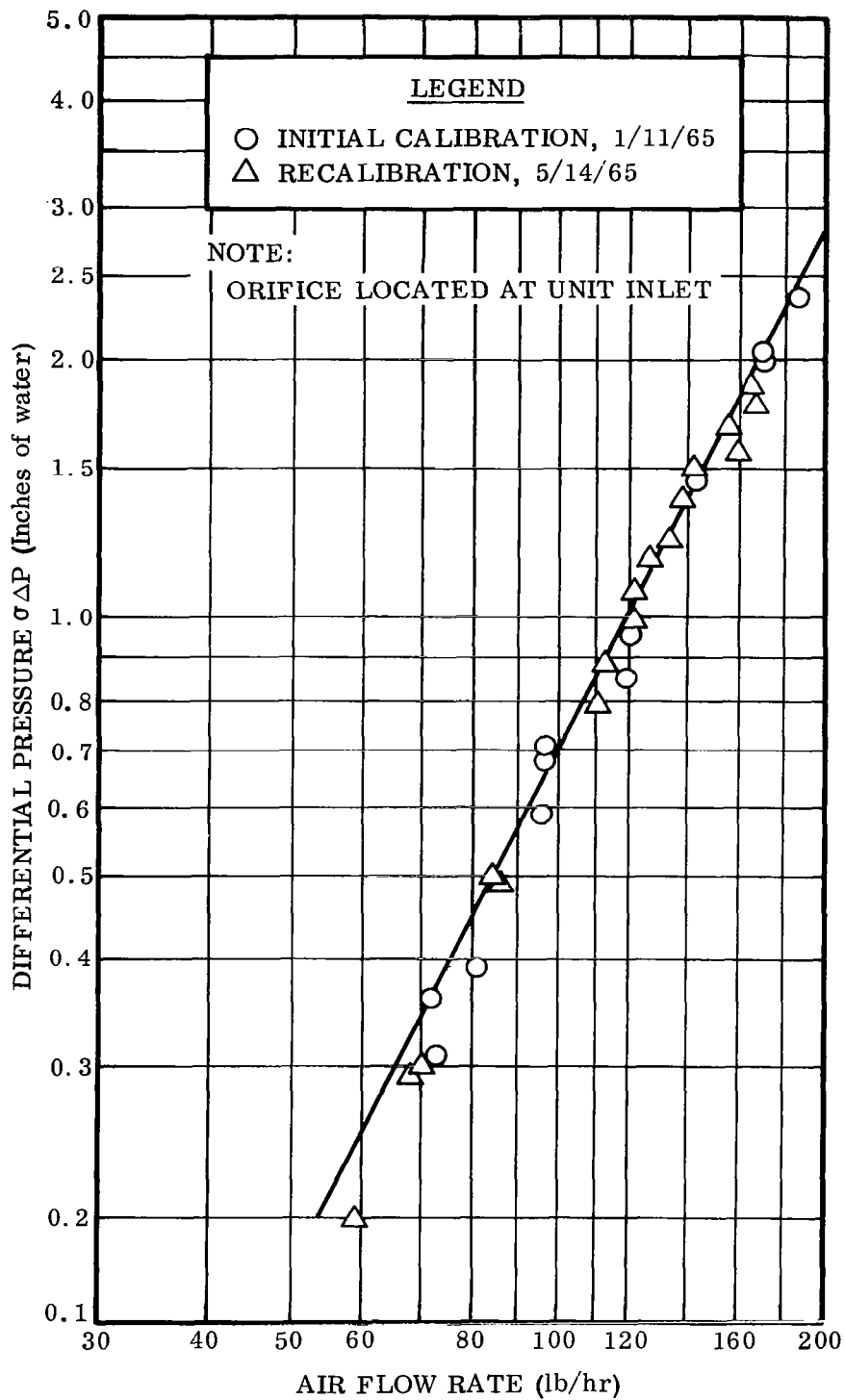


Figure A-23. Orifice Calibration, CO₂ Concentration Unit

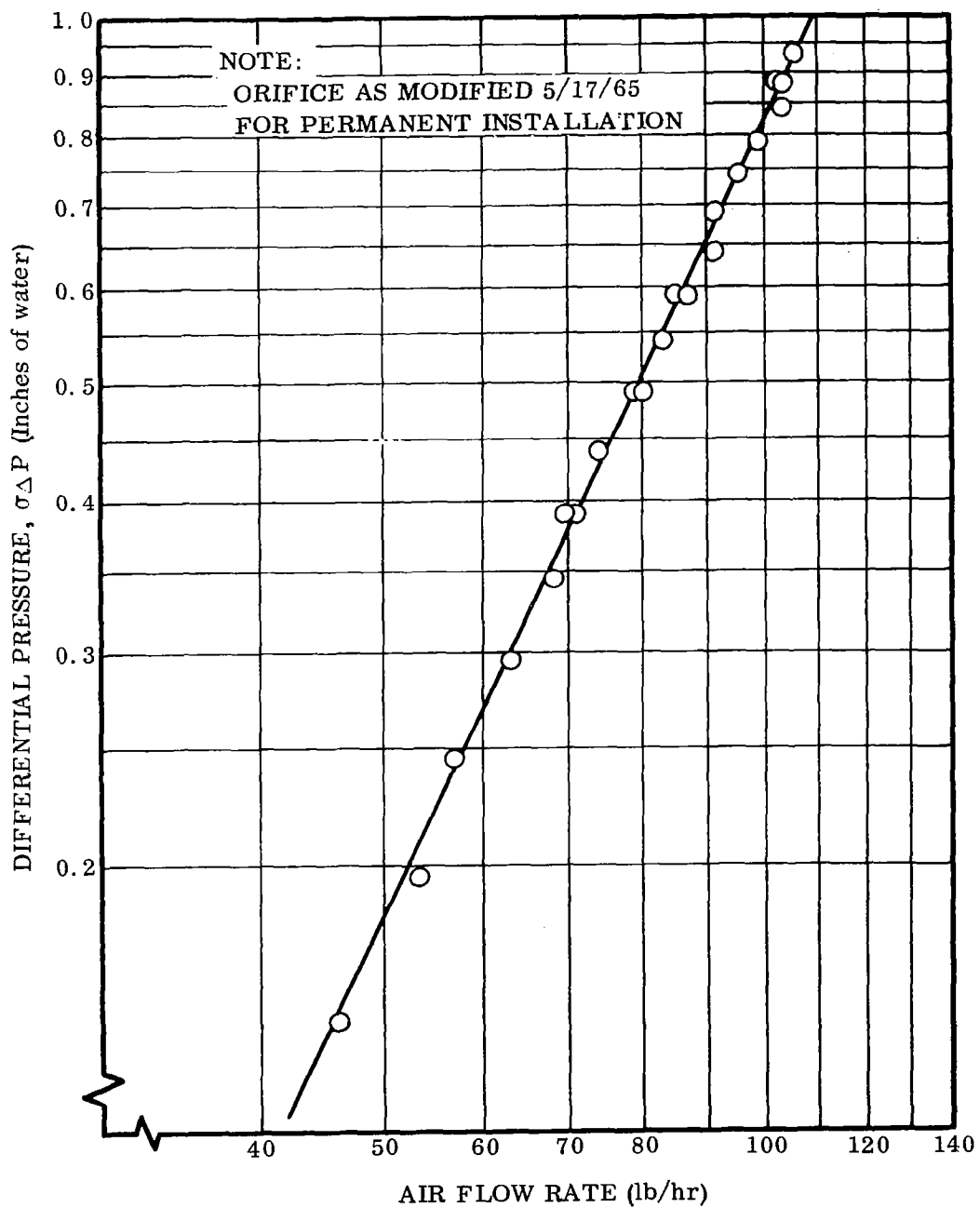


Figure A-24. Orifice Calibration, CO₂ Concentration Unit (Orifice Modified)

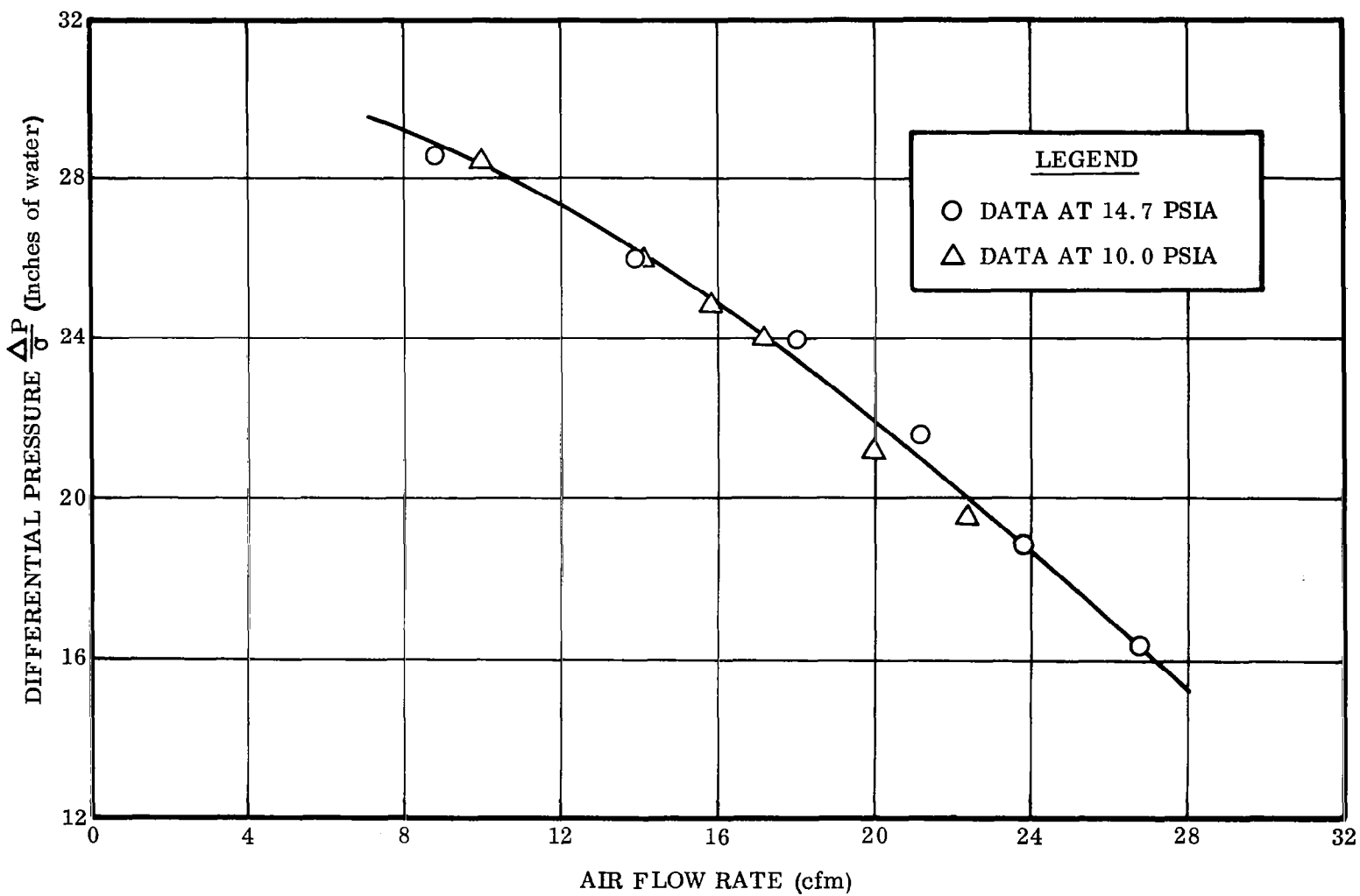


Figure A-25. Blower Performance, CO₂ Concentration Unit

NOTES:

PUMP MFR: AIR CONTROL INC
 MODEL NO: G-5
 (SERIES CONNECTED)

GEAR MOTOR MFR: WESTERN GEAR CORP
 MODEL NO. 35YH69RP146A
 MOTOR: 208 V/3-PH/400 CPS
 SHAFT SPEED: 2280 RPM (OUTPUT)

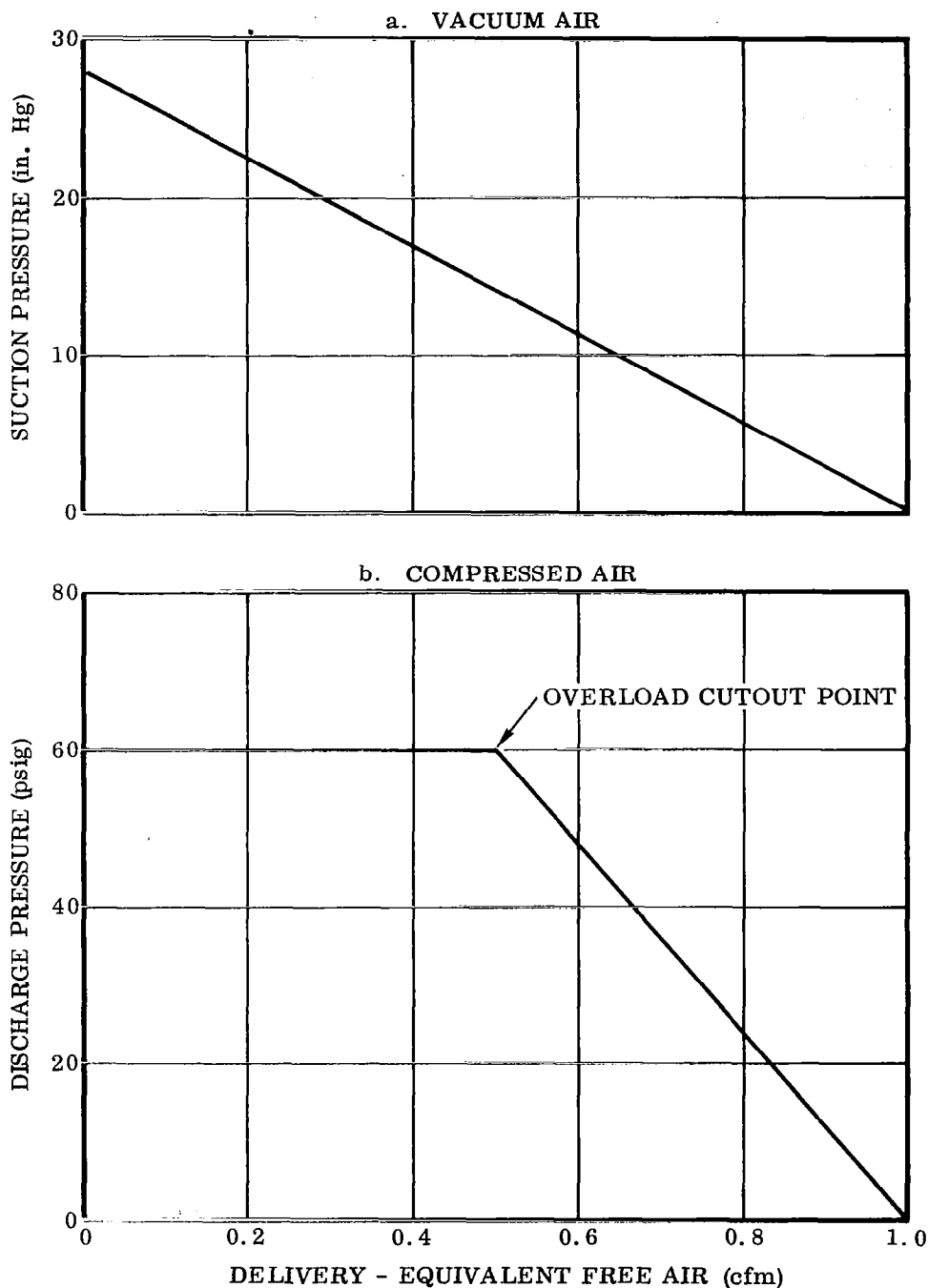


Figure A-26. Pump Performance, CO₂ Concentration Unit

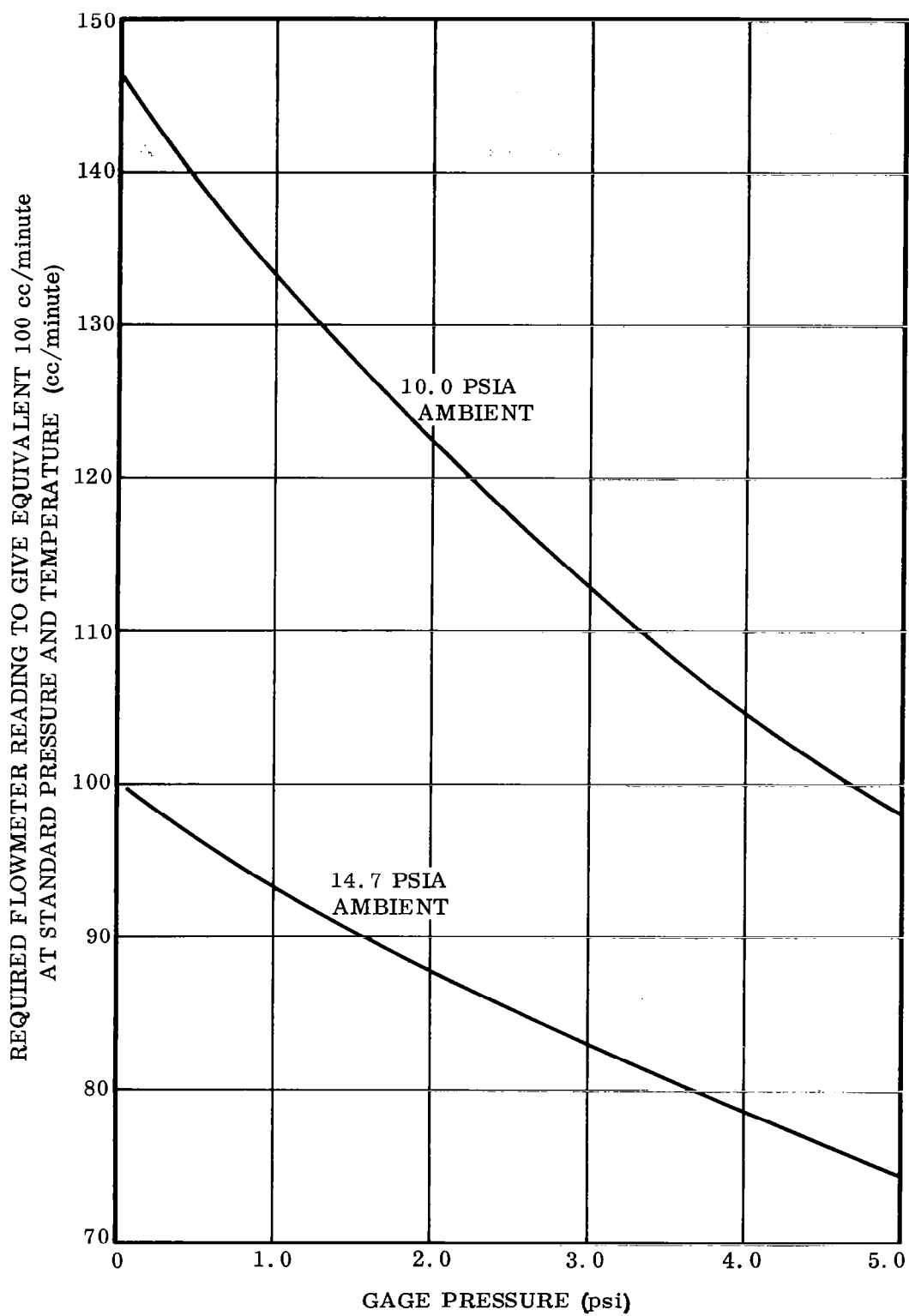


Figure A-27. Pressure Correction Curve, Beckman Hygrometer,
CO₂ Concentration Unit

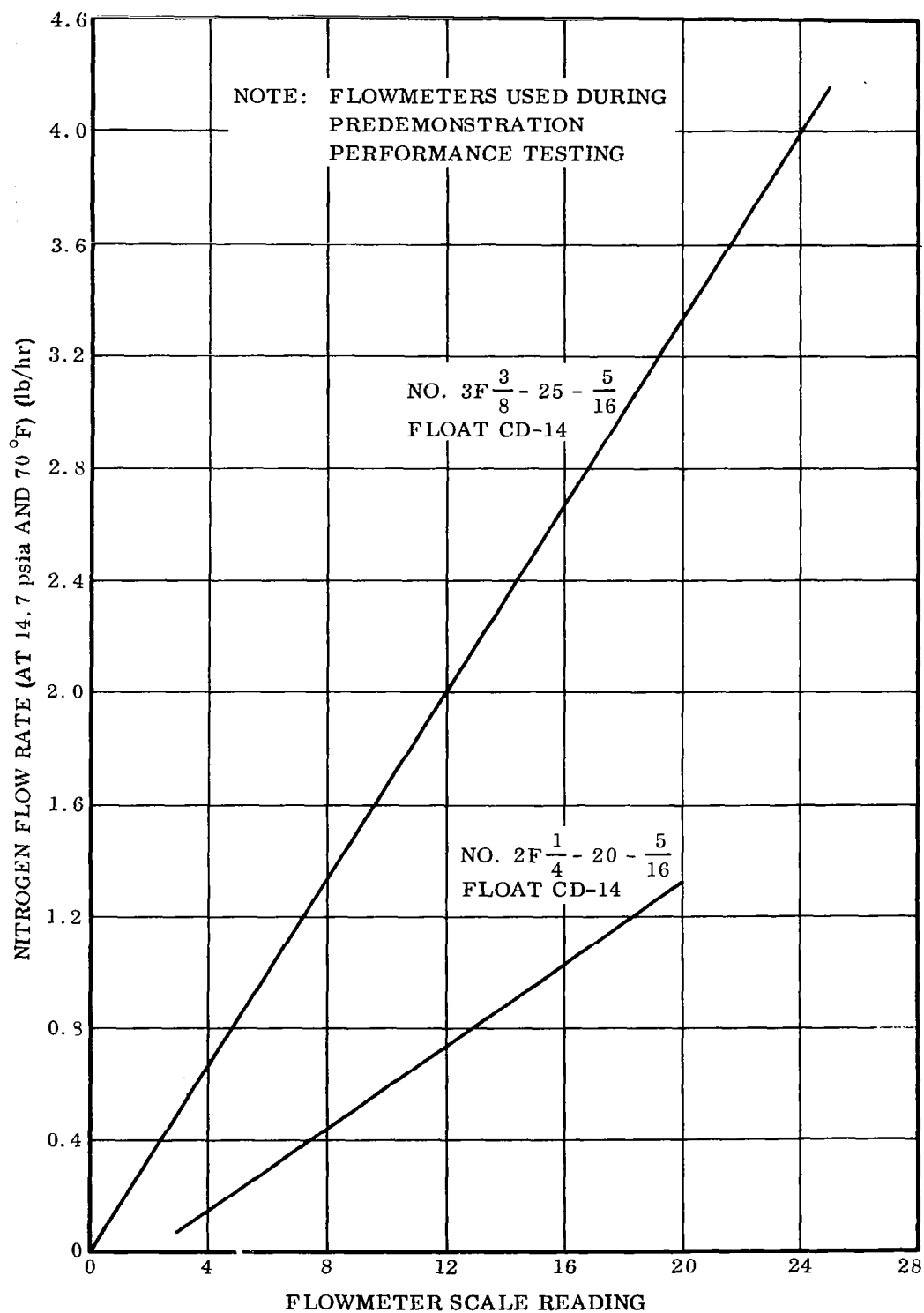
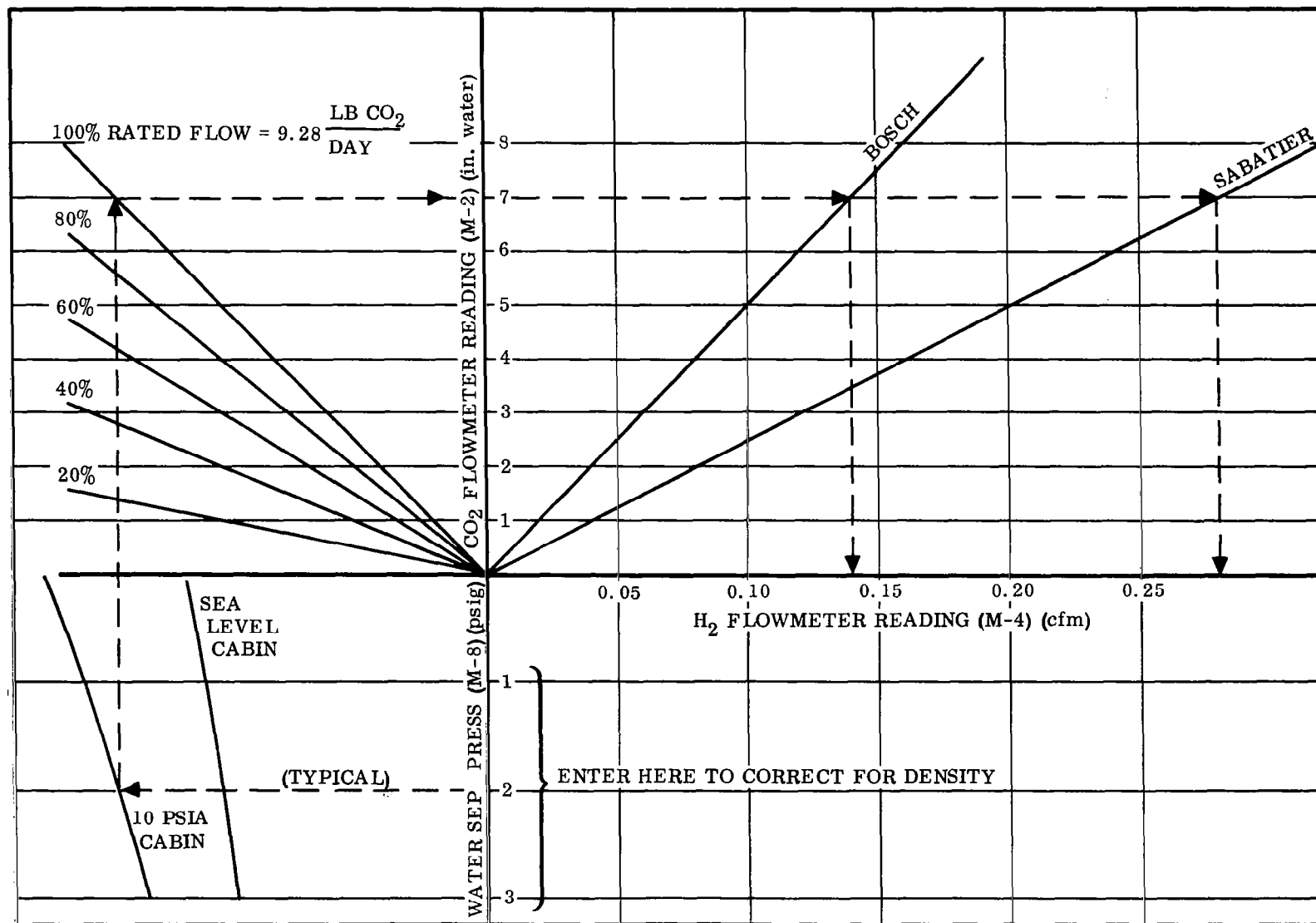


Figure A-28. Flowmeter Calibration, Fisher-Porter Flowmeter,
Tri-flat Tube

Figure A-29. Feed Flowmeter Settings, CO₂ Reduction Unit

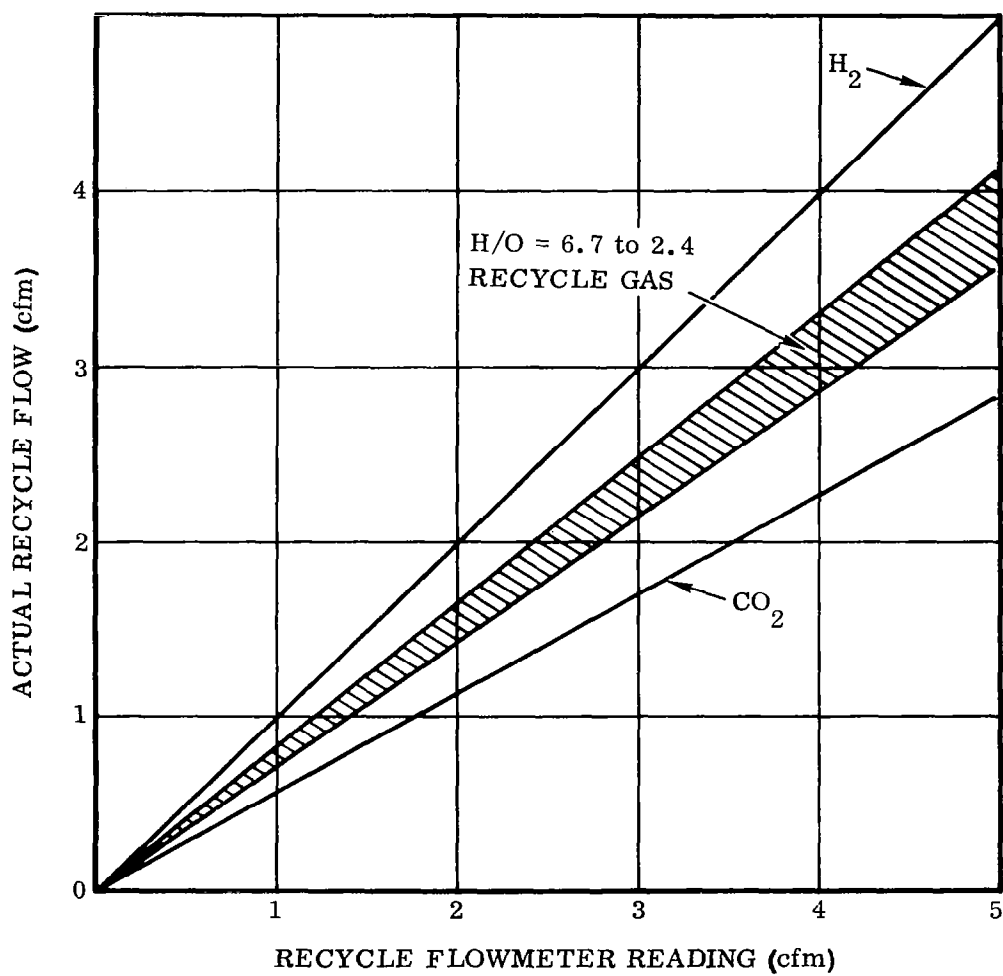


Figure A-30. Recycle Flowmeter Calibration, CO_2 Reduction Unit

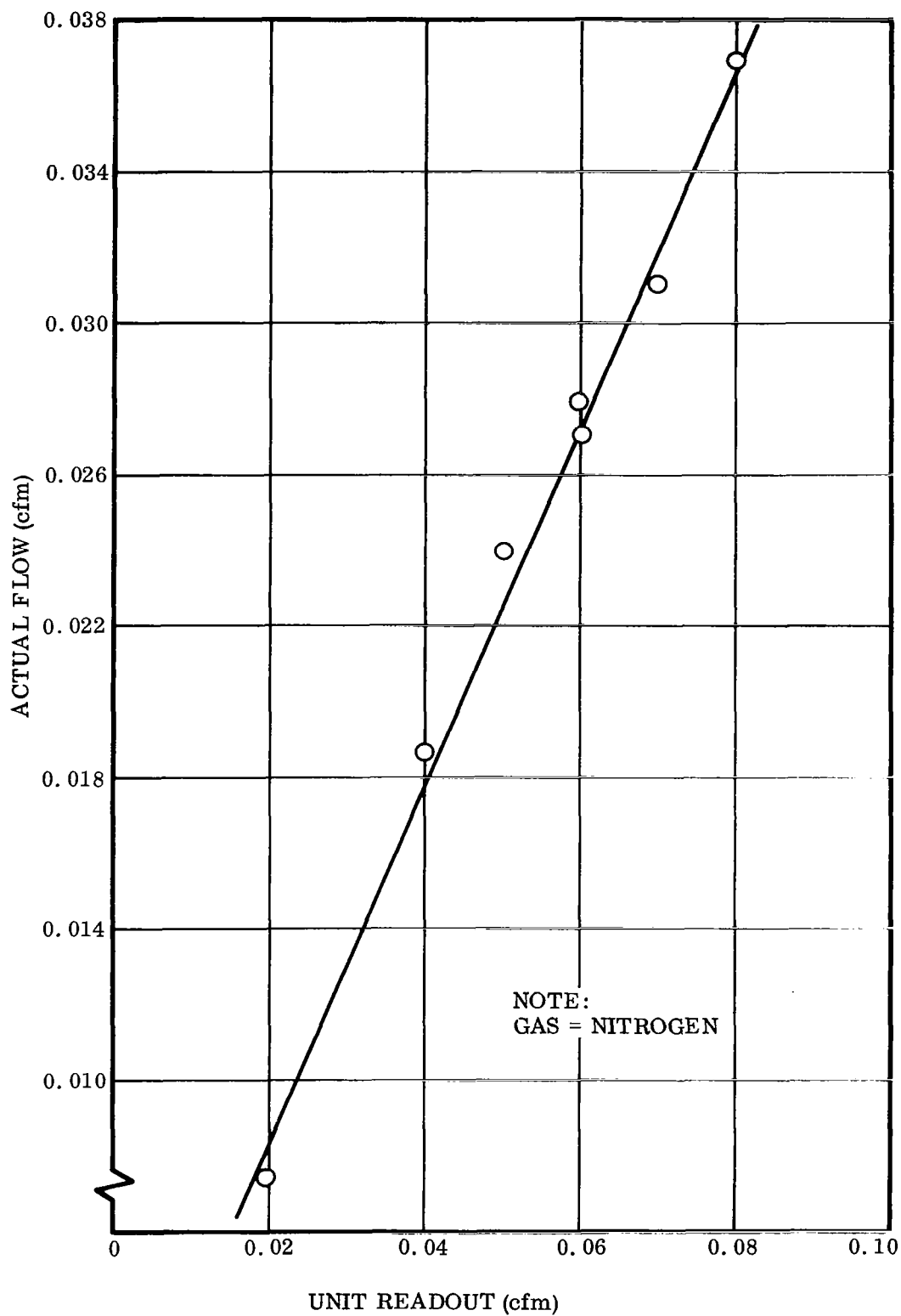


Figure A-31. Purge Flow Calibration, CO₂ Reduction Unit

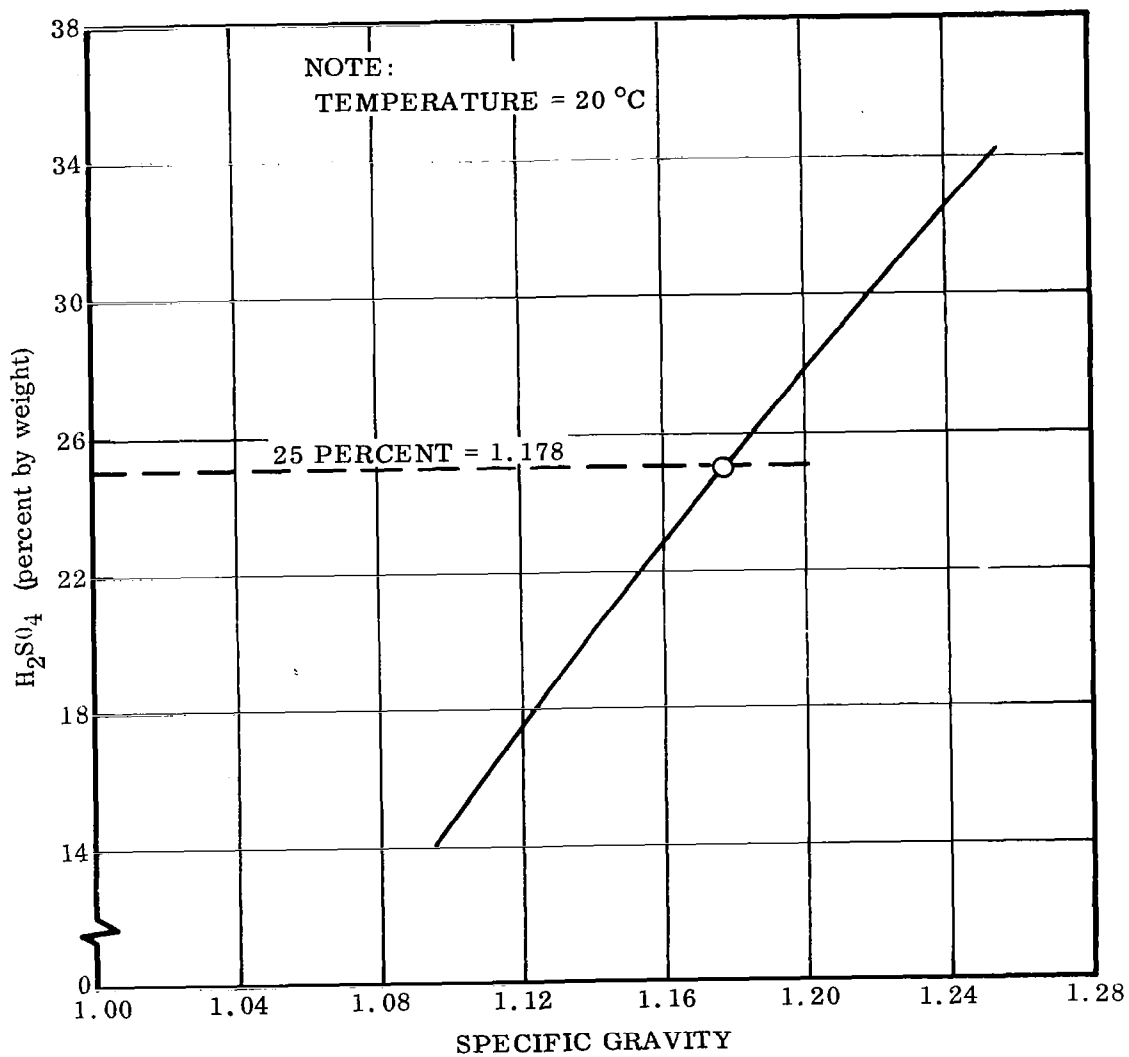


Figure A-32. Specific Gravity of Aqueous Sulfuric Acid Solutions

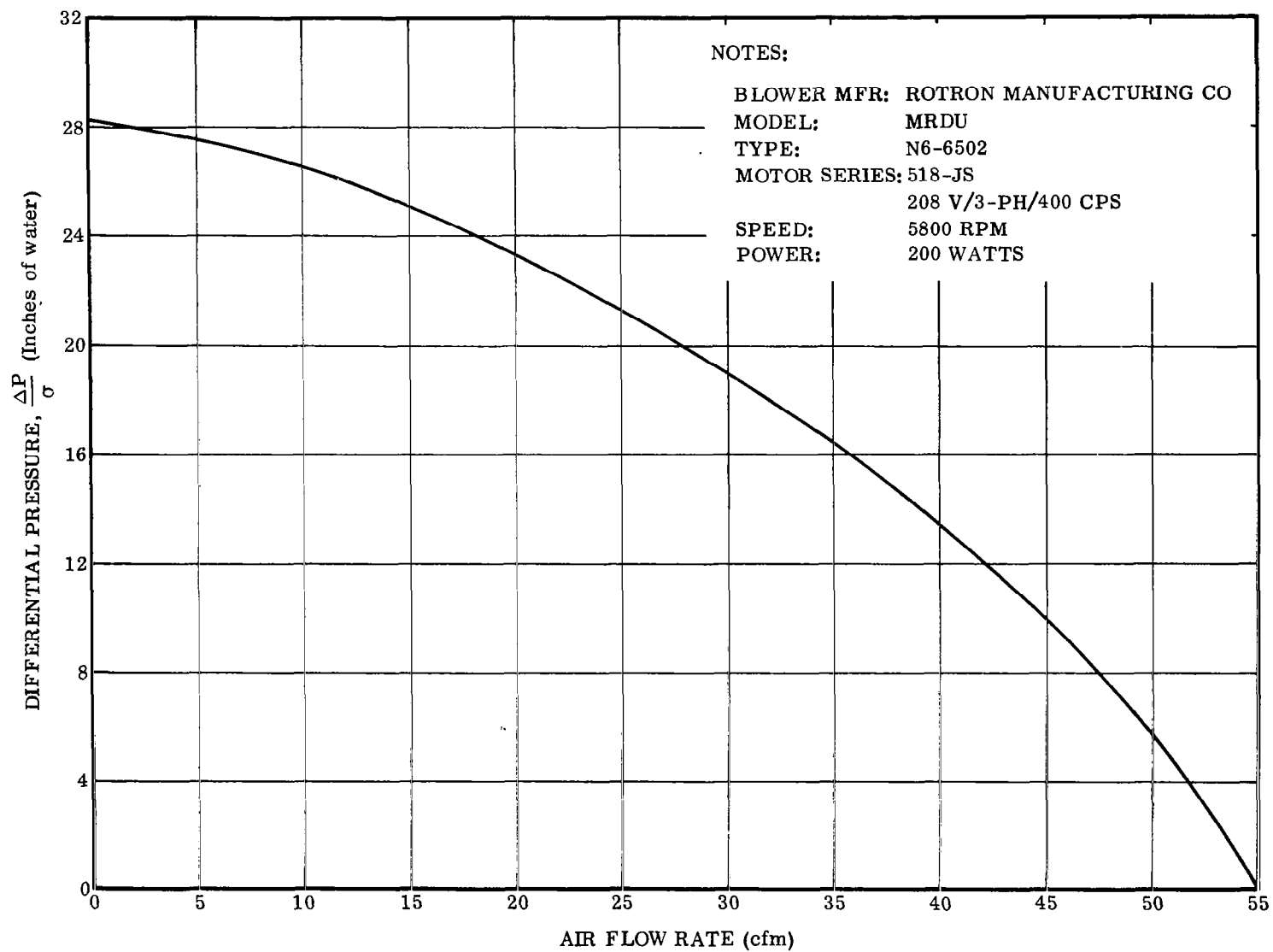


Figure A-33. Blower Performance, Catalytic Burner Boost Blower

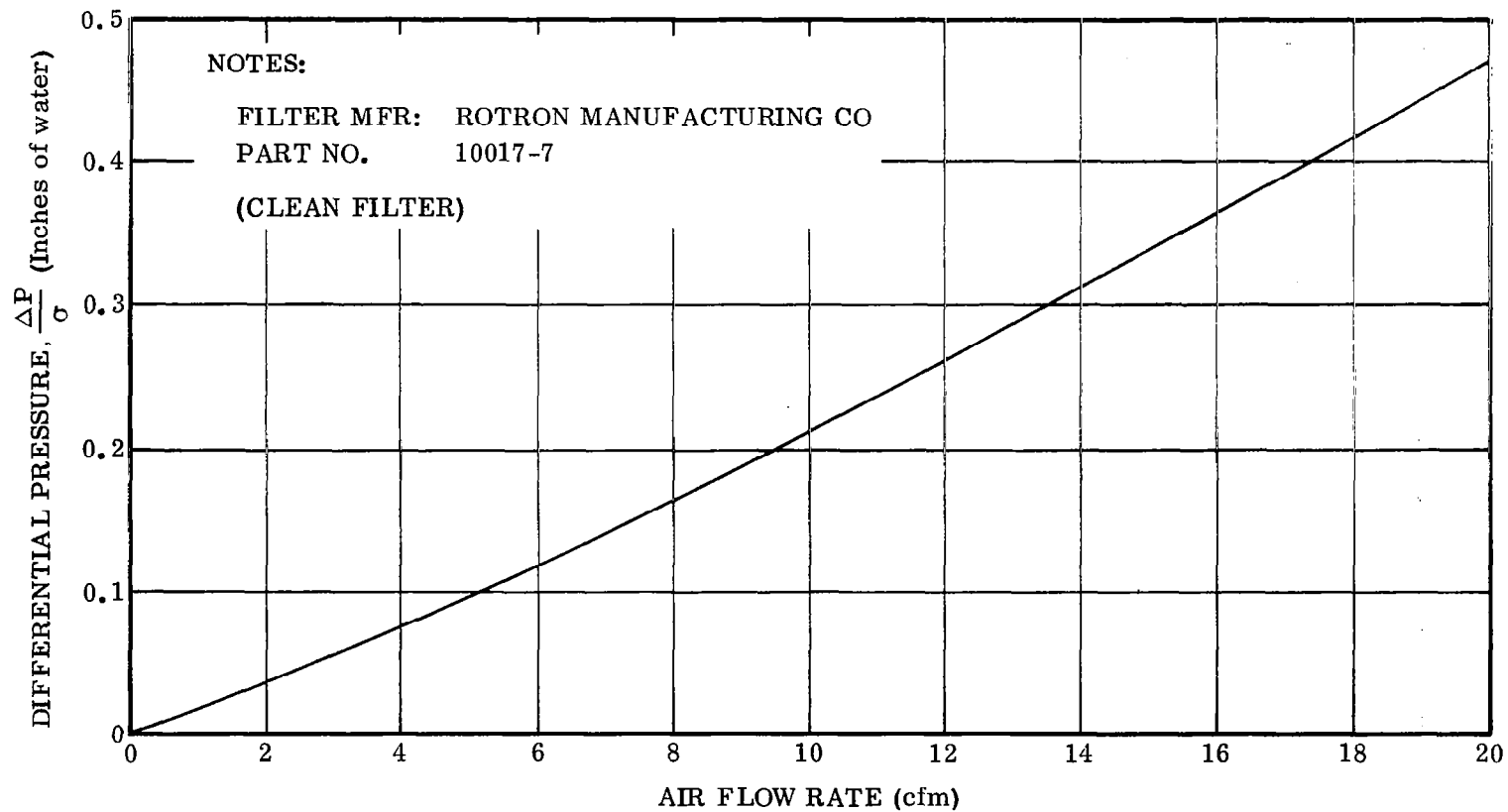


Figure A-34. Filter Pressure Drop Characteristics, Activated Carbon Adsorption Filter (on Catalytic Burner Boost Blower)

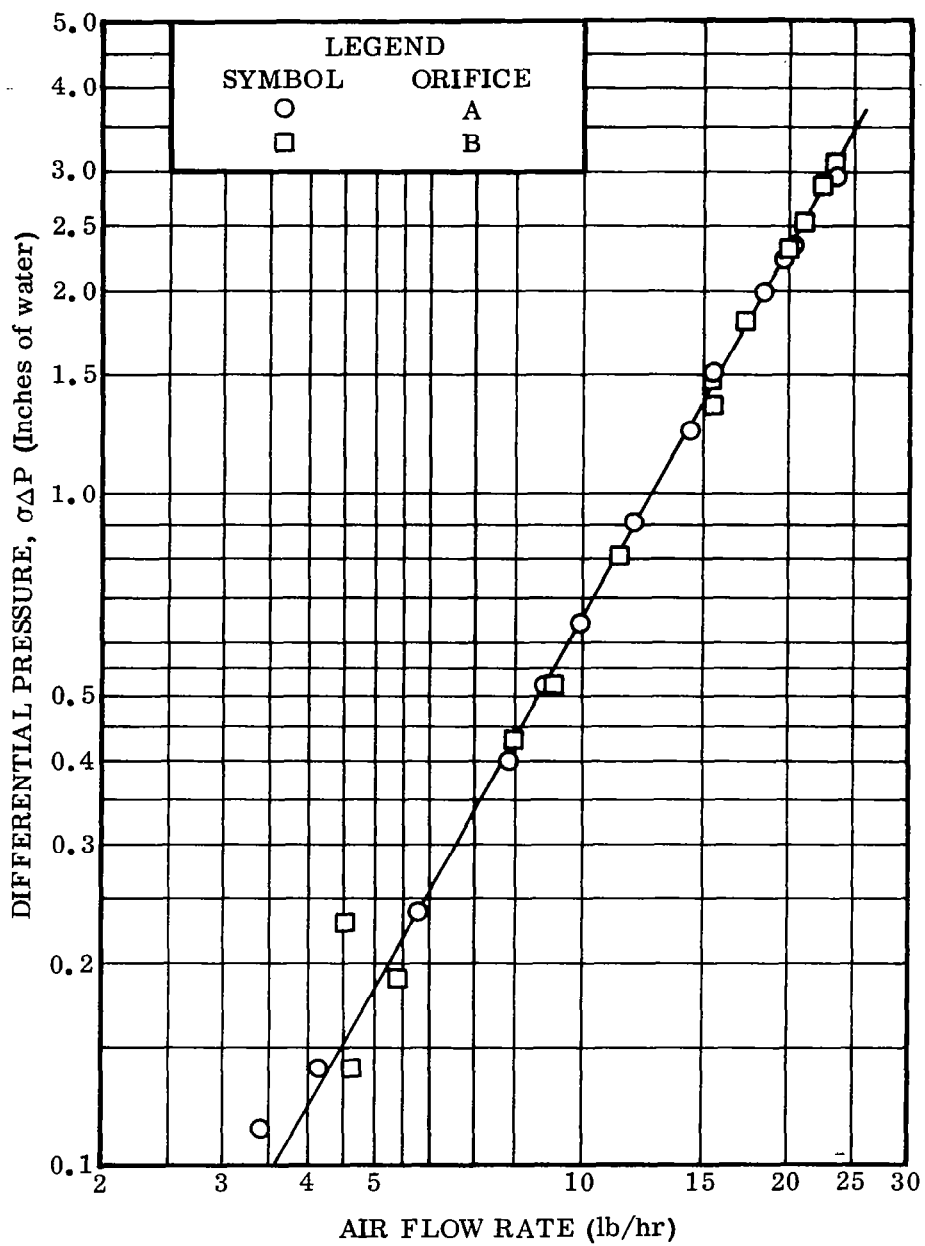


Figure A-35. Orifice Calibration, Catalytic Burners

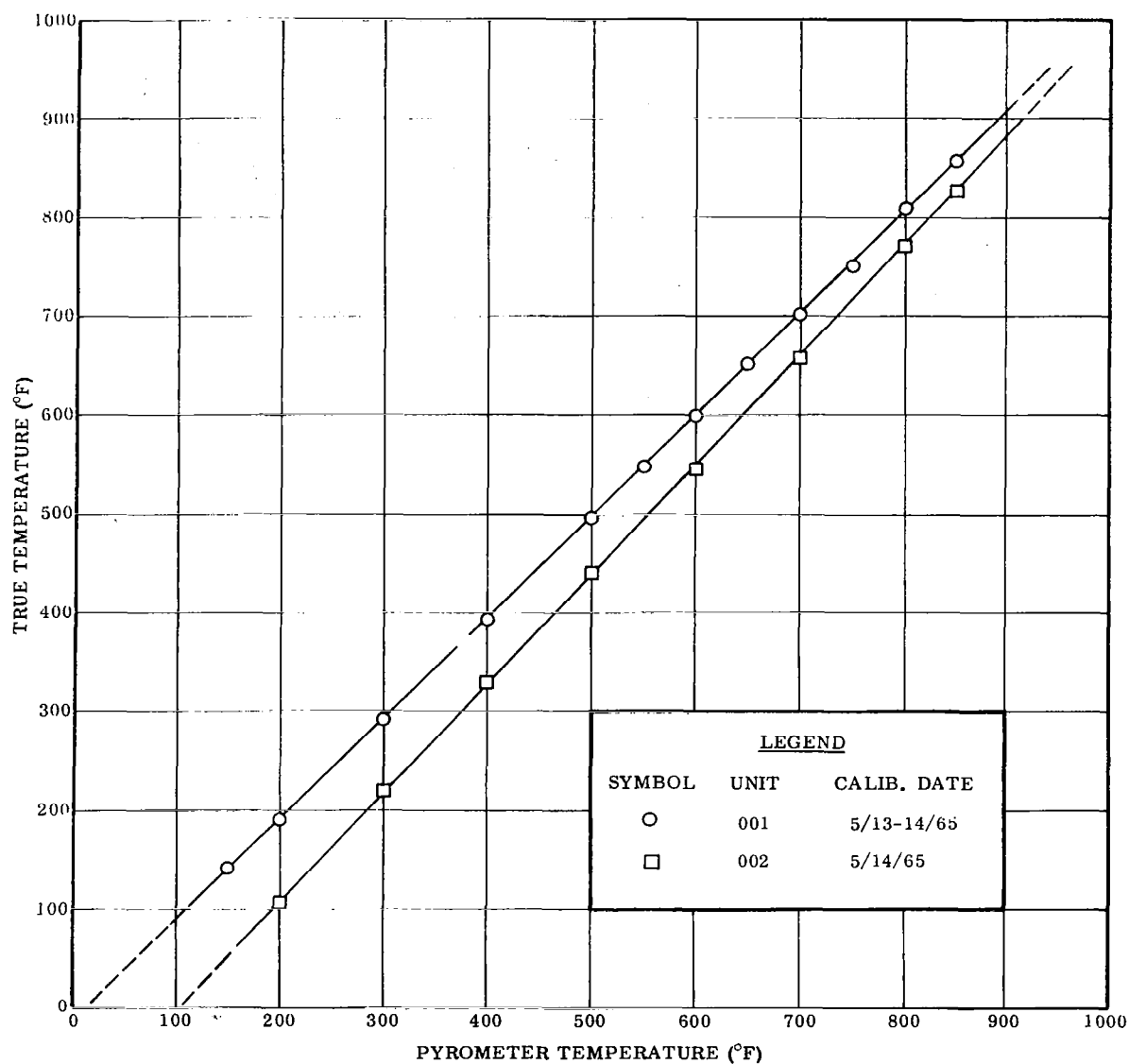


Figure A-36. Pyrometer Calibrations, Catalytic Burners

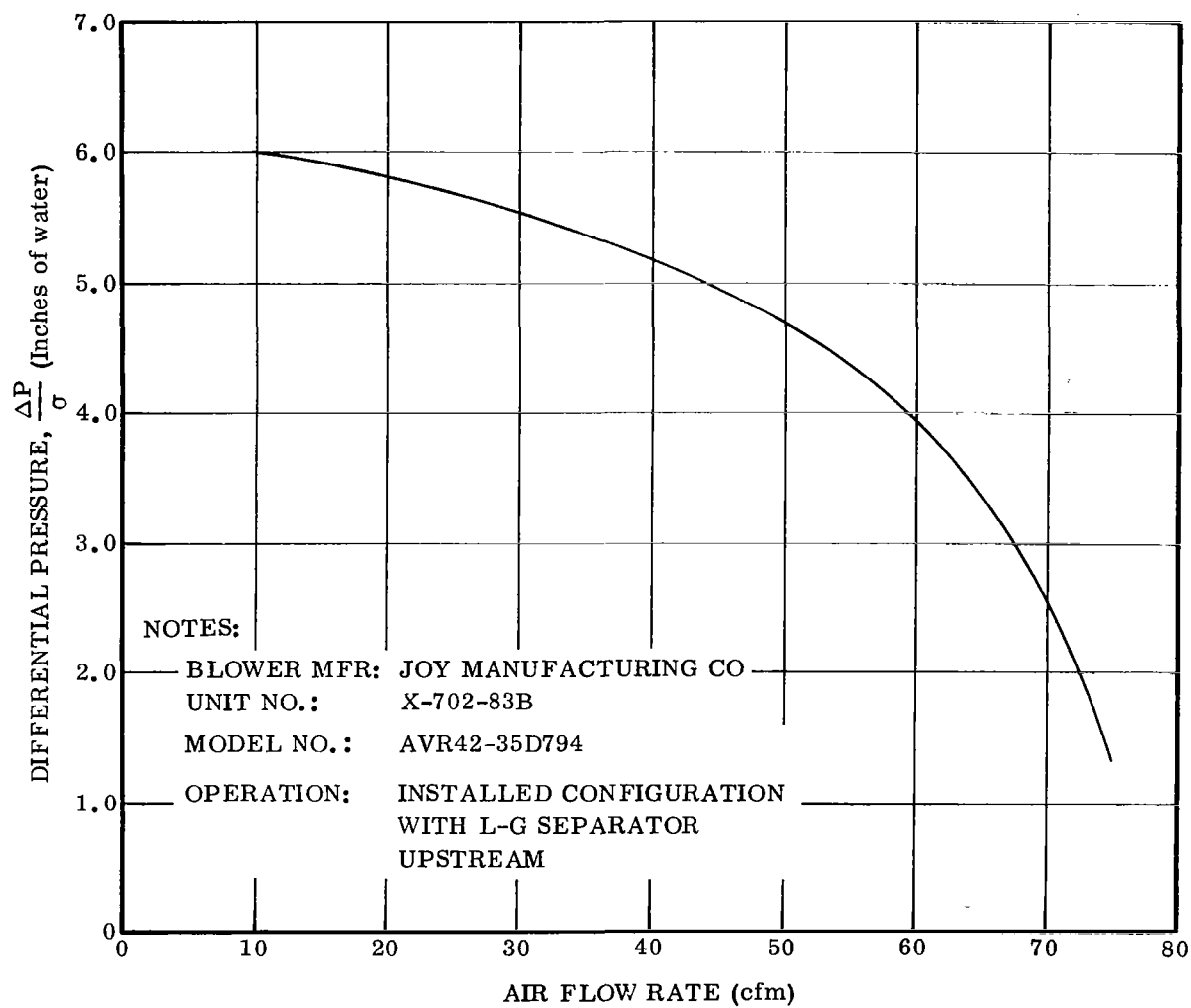


Figure A-37. Blower Performance, Water Recovery Units

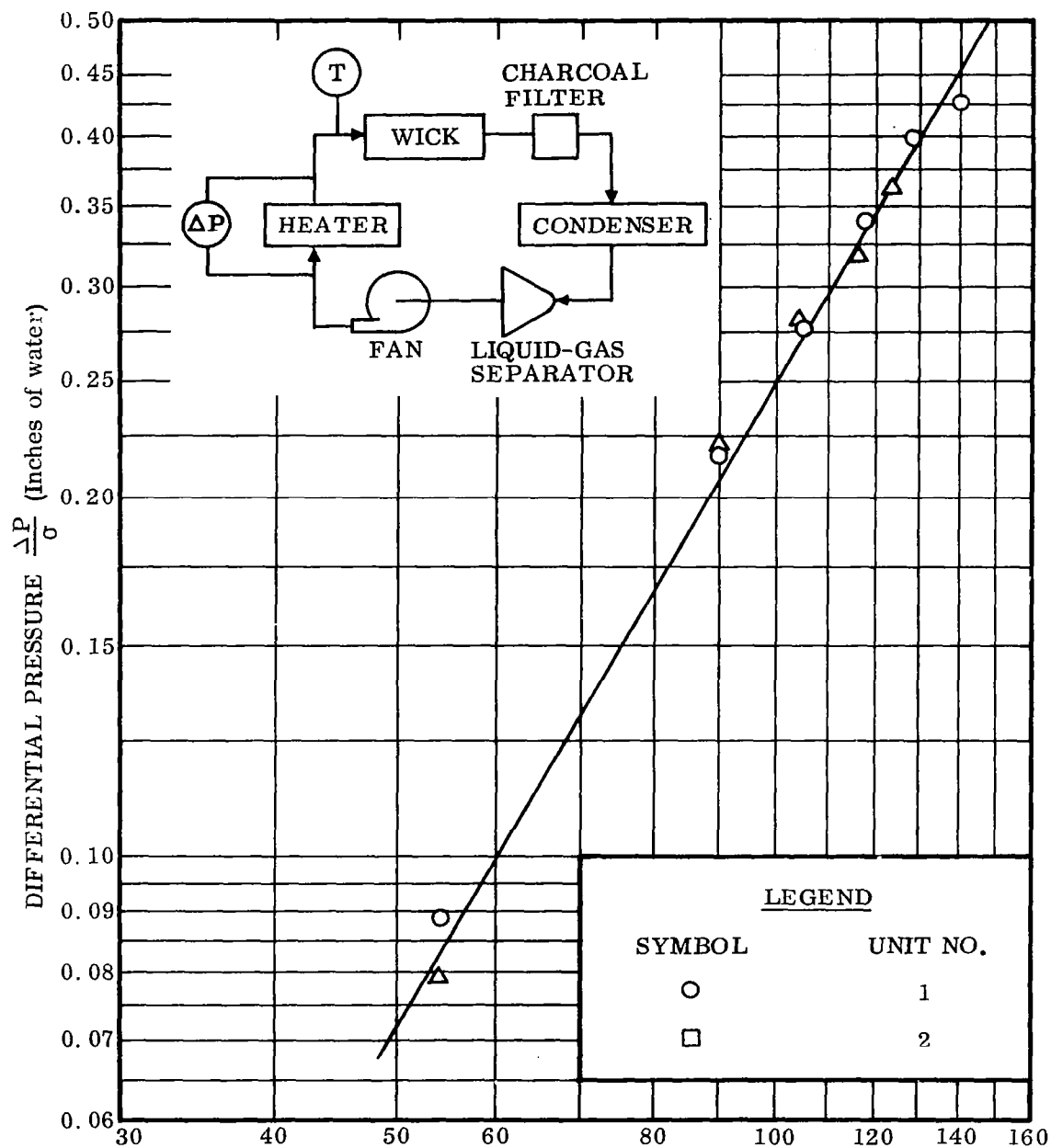


Figure A-38. Flow Calibration, Water Recovery Units

APPENDIX B
DOCUMENT SUMMARY

B.1 CONVAIR PROCUREMENT SPECIFICATIONS

64-02001	Spacecraft Cabin Test Hull, Life Support System
64-02002	Spacecraft Cabin Test Hull, Life Support System, Specification for
64-02003	CO ₂ Reduction Unit, Life Support System, Specification for
64-02004	CO ₂ Concentration Unit, Life Support System, Specification for
64-02005	Water Electrolysis Unit, Life Support System, Specification for
64-02006	Waste Management System, Life Support System, Specification for
64-02007	Pyrolysis Unit, Water Reclamation, Life Support System, Specification for
64-02008	Waste Water Vacuum Distillation Unit, Water Reclamation, Life Support System, Specification for
64-02009	Filtration Water Recovery System, Life Support System, Specification for
64-02010	Cabin Air Heat Exchanger, Life Support System, Specification for
64-02011	Fluid Heating and Pumping Unit, Specification for
64-02012	Coolant Fluid Heater, Life Support System, Specification for
64-02013	Fluid Cooling and Pumping Unit
64-02014	Food Management System, Life Support System, Specification for
64-02015	Specification Control Drawing -- Positive Expulsion Tank
64-02016	Cabin Air Heat Exchanger and Water Separator, Life Support System, Specification for
64-02017	Temperature Control System
64-02018	Waste Heat Air Evaporation Water Recovery Unit
64-02019	Personal Hygiene System
64-02020	Heat Exchanger -- LSS Test Bed
64-02021	Catalyst Bed -- Hopcalite Pack
64-02023	High Temperature Catalytic Burner, LSS, Specification for
64-02024	Cabin Air Water Separator, LSS, Specification for

B.2 CONVAIR REPORTS

64-26200	Spacecraft System Model Definition for NASA Life Support System Design Criteria
64-26201	System Specification for NASA Contract No. NAS 1-2934 Life Support System
64-26202	Effects on Cabin Atmosphere of Crew Metabolic Rate Excursions, Contract No. NAS 1-2934
64-26203	Oxygen Recovery System Evaluations for Space Flights of One Year Duration
64-26204	Atmospheric Contaminant Control Subsystem Evaluation for Space Flights of One Year Duration
64-26205	Waste Management System Evaluation for Space Flights of One Year Duration
64-26206	Water Management Subsystem Evaluation for Space Flights of One Year Duration
64-26207	Thermal Control Subsystem Specification
64-26208	Thermal Control Analysis for NASA Contract No. NAS 1-2934, LSS for Space Flights of Extended Time Periods
64-26209	Food Management System Evaluation and Subsystem Specification for Space Flights of One Year Duration
64-26210	Waste Management Subsystem Specification for Space Flights of One Year Duration
64-26211	Water Management Subsystem Specification for Space Flights of One Year Duration
64-26212	Personal Hygiene System Evaluation and Subsystem Specification for Space Flights of One Year Duration
64-26213	Atmospheric Stores System Evaluation for Space Flights of One Year Duration
64-26214*	Instrumentation and Controls Subsystem Specification for Space Flights of One Year Duration
64-26215	Atmospheric Control Subsystem Specification for Space Flights of One Year Duration

*Inadvertently released as Report No. 64-26140

64-26216	Life Support Integration Summary for Space Flights of One Year Duration
64-26217	Prediction of Ventilation Jet Characteristics for a Zero Gravity Environment
64-26218	LSS Test Bed -- Pressurization Description and Method of Operation
64-26219	Water Management Subsystem, Operational Description
64-26220	Integration of Pressure Suits with the Life Support System for Space Flights of One Year Duration
64-26221	Life Support System Integrated Test Plan
64-26222	Test Procedure for Life Support System Test Bed
64-26223	LSS Project Cleaning Requirements and Cleanliness Controls
64-26224	Control of Cabin O ₂ , N ₂ and CO ₂ Concentrations
64-26225	Spares Selection Guidelines
64-26226	Test Bed Acoustic Treatment for Room Reverberation Control
64-26227	Preliminary System Testing at 10 psia
64-26228	Final Demonstration and Test Report
64-26229	Redesign of the CO ₂ Reduction Unit
64-26230	Handbook of Operating Instructions
64-26231	Liquid/Gas Separation Mechanisms
64-26232	Life Support Equipment Modification and Advanced Testing
64-26233	Master Document Summary

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other nonaerospace applications. Publications include Tech Briefs; Technology Utilization Reports and Notes; and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546